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The Fault Diagnosis for Power System Using Fuzzy Petri Nets

Abstract*. A rapid and correct fault diagnosis is crucial for power system network. As the complexity of power system increases, fault diagnosis becomes very difficult task in the limited short time. This situation has made it necessary to develop intelligent systems to support operators in their decision making process. The paper mainly investigates fault diagnosis of power system by using Fuzzy Petri Nets (FPN) technology. FPN is used for accurately fault diagnosis in power system when some incomplete and uncertain alarm information of protective relays. It is shown from several cases that the faulted system elements can be diagnosed correctly by use of these models. By suggested method, it is possible to decline diagnosis time according to traditional methods. Finally, the suggested method can easily be adapted to different power system network. It is practicable an impressive for fault diagnosis in power system.*

Streszczenie. *W artykule opisano metodę diagnostyki sieci energetycznej przy wykorzystaniu technologii rozmytych sieci Petriego FPN. Pokazano na kilku przykładach prawidłowe wykrycie błędów systemu przy czasie analizy krótszym n iż to oferują systemy tradycyjne. (**Diagnostyka sieci energetycznych przy użyciu rozmytych sieci Petriego**)*

Keywords: Power system, fault diagnosis, intelligent system, fuzzy Petri nets.
Słowa kluczowe: system energetyczny, sieć Petriego, diagnostyka

Introduction

The modern power system is a multi-dimensional dynamic system. It is not always possible to build accurate mathematic models for many problems run across in power systems, or in other words, these problems cannot be well solved by only using available mathematical methods [1, 2]. As a result, various artificial intelligence based techniques, such as expert systems, fuzzy set theory, FPN, artificial neural networks and genetic algorithms have been widely applied in order to solve some problems in power systems [3]. Fuzzy set theory was applied to the network matrix in order to examine the relationship between the operated protective devices and the fault section candidates [4, 5]. However fault diagnosis in power systems still stays unsolved owing to the high speed and accuracy required. The problem is much more difficult in cases of malfunctions of relays and circuit breakers, or multiple faults.

The power system includes components of different time and signal concepts, leading to interactions between the continuous dynamics and discrete events. The modelling of power systems thus becomes a highly challenging task as these interactions are pivotal in the design process. Components such as generators, load exhibit continuous dynamics where as event driven discrete behaviour results from logic rules that govern the system and which include protection devices, on load tap-changing transformers, power electronic switches [6, 7].

Fault detection in power system is a procedure in which the faulted sections of system are diagnosed based on the data acquired by the relays and breakers stored in Supervisory Control and Data Acquisition (SCADA) system [8]. Occurring serious faults in power system, many warning information is sent to the control room by the protection devices of power system. In these cases, it is necessary for the operators to accurately and quickly diagnose the reason and location of the fault and also the faulted elements.

The Petri nets (PN) have been used for modelling and detection of faults and their location in power systems. PN was originally developed by Carl Adam Petri, German, in his doctoral dissertation “Communication with automata” in 1962. PN theory is based on the concept that the relationships between the components of a system, which shows asynchronous and concurrent activities, can be represented by a net [9, 10]. PN is a significant tool for analyzing the behaviors of many different systems such as computer systems, power systems and manufacturing systems.

Petri nets fundamentals

PN are used to study with different characteristics, for instance concurrent, asynchronous, distributed, parallel, non-deterministic or stochastic system [11]. For that reason PN are very useful for the analysis of various industrial processes such as production facilities, modelling of electrical system and computational system. A PN has of two types of elements, those are; nodes and arcs, the first group is divided into transitions and places, that represent the states and events that allow moving from one state to another [12]. Figure 1 shows all elements of PN.

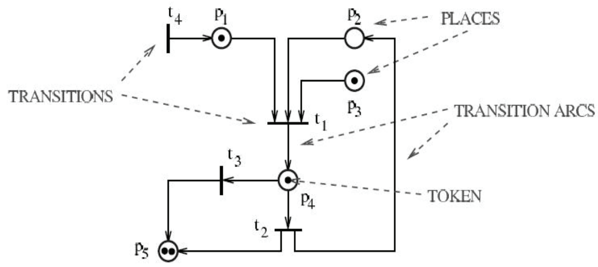

Fig.1. The graphical representation of PN

A PN is a bipartite directed weighting multi-graph, which is formalized based on the bag theory. A PN structure is a 6-tuple [13] with PN = (P, T, I, O, F, M), where

(1) $P = \{p_1, p_2, \ldots, p_m\}$ is a finite nonempty set of place node;

(2) $T = \{t_1, t_2, \ldots, t_m\}$ is a finite nonempty set of transition node; $P \cup T \neq \emptyset$, and $P \cap T = \emptyset$;

(3) $I : (PXT) \rightarrow N$ is the input function, to describe the mapping from transition nodes to bags of place nodes, where N is the set of nonnegative integers;

(4) $O : (PXT) \rightarrow N$ is the output function, to represent the mapping from transition nodes to bags of place nodes;

(5) $F \subseteq (PXT) \cup (TXP)$ is the set of directed arcs.

(6) $M : P \rightarrow N$ is the initial marking, for the mapping from place node to the nonnegative integers N. M(p) indicates the number of tokens on place node p under the marking M.

A marking is an assignment of tokens to the places of a PN. A token is a primitive concept for PN (like places and transitions). Tokens are assigned to, and can be thought to reside in, the places of a PN. The number and position of tokens may change during the execution of a PN. The tokens are used to define the execution of a PN.

Fuzzy petri nets (FPN)

Fuzzy logic approaches have been applied to power system fault diagnosis in [14, 15]. These techniques offer the possibility to model inexactness and uncertainties created by protection device operations and incorrect data. FPN are defined on the basis of generalized PN. A FPN structure can be defined as an 8-tuple [16]; with FPN = (P, T, D, I, O, f, α, β), where

(1) $P = \{p_1, p_2, \ldots, p_m\}$ is a finite set of places;
(2) $T = \{t_1, t_2, \ldots, t_m\}$ is a finite of set transitions;
(3) $D = \{d_1, d_2, \ldots, d_m\}$ is a finite set of propositions, which meet $P \cap T \cap D = \emptyset$ and $|P| = |D|$;
(4) $I : T \rightarrow P^{\infty}$ is the input function, a mapping from transitions to bags of places;
(5) $O : T \rightarrow P^{\infty}$ is the output function, a mapping from transitions to bags of places;
(6) $f : T \rightarrow [0, 1]$ is an association function, a mapping from transitions to real values between zero and one.
(7) $\alpha: P \rightarrow [0, 1]$ is an association function, a mapping from places to real values between zero and one.
(8) $\beta : P \rightarrow D$ is an association function, a directive mapping from places to propositions.

The tokens value of a place p_i, $p_i \in P$, is denoted by $\alpha(p_i)$, where $\alpha(p_i) \in [0, 1]$. If $\alpha(p_i) = y_i$, $y_i \in [0, 1]$, and $\beta(p_i) = d_i$, then it indicates that the degree of truth of proposition d_i is y_i. Let λ be a threshold value, where $\lambda \in [0, 1]$, if the degree of truth of proposition d_j is y_j, $y_j \in [0, 1]$.
Case 1: if $y_j \geq \lambda$, then the proposition can be fired.
Case 2: if $y_j < \lambda$, then the proposition cannot be fired.
If $f(t_i) = \mu_i$, $\mu_i \in [0, 1]$, it represents the strength of the belief of the transition. The larger the value, the more the rule is believed. A fuzzy production rule is a rule which describes the fuzzy relation between two propositions. The general formulation of the *i* th fuzzy production rule is as follow:

(1) $$R_i : \text{IF } d_j \text{ Then } d_k \ (CF = \mu_i)$$

$X = \{x_1, x_2, \ldots x_m\}$, $Y = \{y_1, y_2, \ldots y_m\}$, $G = \{g_1, g_2, \ldots g_m\}$, are input places, hidden places and output places of FPN. The input places provide a vector of observation. The truth values of the propositions of the hidden and output can be attained by successive application of the well-know max-min compositional rule [17].

(2) $$Y = \max_{xi} \min \ (X(xi), R(xi, yi))$$

Where a fuzzy relation $R: X \times Y \rightarrow [0, 1]$ describes all implications by transition truth values. Two simple FPN model is shown in figure 2 which model the rules OR - AND. AND rule: If p_1 and p_2 then p_3, (with the certain factor is μ) it may be assumed that the values of p_1 and p_2 are x_1 and x_2. The value of p_3 is $x_3 = \min(x_1, x_2, \mu)$. OR rule: If p_1 or p_2 then p_3, it may be assumed that the values of p_1 and p_2 are x_1 and x_2, μ_1, μ_2 is the certain factor value of transition T_1, T_2. The value of p_3 is $x_3 = \max(\min(x_1, \mu_1), \min(x_2, \mu_1))$.

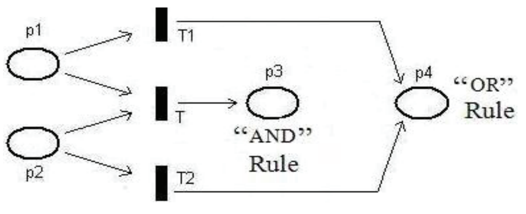

Fig.2. The FPN model of the rules AND-OR

Reachable graph for two simple FPN model is shown in figure 3.

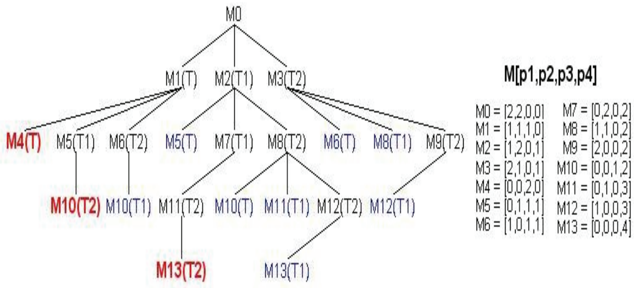

Fig.3. Reachable graph for two simple FPN model

Modelling the operation of protection system by FPN

The objective of this section concentrates on modelling of fault diagnosis using FPN model. For demonstration ends, we consider a simplified power system. A part of power system is shown in figure 4 with nine lines ($Line_1$, $Line_2$, ……., $Line_8$, $Line_9$) and eighteen Circuit Breakers (CB_1, CB_2, ……., CB_{17}, CB_{18}).

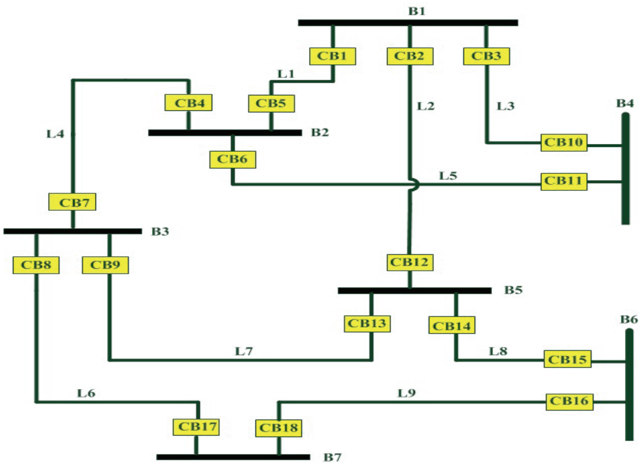

Fig.4. A simple part of power system

We have 18 Circuit Breaker (CB) and 18 protective relays corresponding: CB_1, R_1, CB_2, R_2, CB_3, R_3, CB_4, R_4, CB_5, R_5, CB_6, R_6, CB_7, R_7, CB_8, R_8, CB_9, R_9, CB_{10}, R_{10}, CB_{11}, R_{11}, CB_{12}, R_{12}, CB_{13}, R_{13}, CB_{14}, R_{14}, CB_{15}, R_{15}, CB_{16}, R_{16}, CB_{17} R_{17}, CB_{18} R_{18}. Consider above power system, we take Line 3 (L_3) as a simple.

Set up the rule functions

Use FPN with the uncertain information of circuit breakers and relays. Imagine the signal about the status of CB and relay, but the operators are not sure about information.

Rule1: IF the operated R_3 and trip circuit CB_3 are detected in the same time with the certain factor μ_1, then the value of this event is y_1. P_{11} is the output places of rule.
Rule2: IF the operated R_{10} and trip circuit CB_{10} occur in the same time with the certain factor μ_2, then the value of this event is y_2. P_{12} is the output places of rule.
Rule3: IF the operated R_6 and trip circuit CB_6 occur in the same time with the certain factor μ_3, then the value of this event is y_3. P_{13} is the output places of rule.
Rule4: IF the operated R_5 and trip circuit CB_5 occur in the same time with the certain factor μ_4, then the value of this event is y_4. P_{14} is the output places of rule.

Rule5: IF the operated R_{12} and trip circuit CB_{12} occur in the same time with the certain factor μ_5, then the value of this event is y_5. P_{15} is the output places of rule.
Rule6: IF operated protective relay R_3, R_{10} and trip circuit breaker CB_3, CB_{10} are detected, then there is a fault on Line 3. The certain factor is μ_6.
Rule7: IF operated protective relay R_3, R_6 and trip circuit breaker CB_3, CB_6 are detected, then there is a fault on Line 3. The certain factor is μ_7.
Rule8: IF operated protective relay R_{10}, R_5 and trip circuit breaker CB_{10}, CB_5 are detected, then there is a fault on Line 3. The certain factor is μ_8.
Rule9: IF operated protective relay R_{10}, R_{12} and trip circuit breaker CB_{10}, CB_{12} are detected, then there is a fault on Line 3. The certain factor is μ_9.
Rule10: IF operated protective relay R_3, R_6 and trip circuit breaker CB_3, CB_6 and operated protective relay R_{10}, R_5, and trip circuit breaker CB_{10}, CB_5 or operated protective relay R_{10}, R_{12}, and trip circuit breaker CB_{10}, CB_{12} are detected, then there is a fault on Line 3. The certain factor is μ_{10}. FNPN based on AND-OR rule is set up as in Figure 5.

The input places layer provides a vector observation X = (p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_{10}) = (R_3, CB_3, R_{10}, CB_{10}, R_6, CB_6, R_5, CB_5, R_{12}, CB_{12}) the set of hidden variables corresponded to Y = (p_{11}, p_{12}, p_{13}, p_{14}, p_{15}) and (p_{16}, p_{17}, p_{18}, p_{19}) and a set of output variables G = (p_{20}). These truth values are propagated such that we eventually attain the truth values of the target is g (p_{20}), it is the truth value of the fault have occurred on Line 3.

The whole calculation process is as followed example. In figure 5, the first truth value of input places, CB_3, R_3, CB_{10}, R_{10}, CB_6, R_6, CB_5, R_5, CB_{12}, R_{12} be 0.95, 0.9, 0.9, 0.95, 0.95, 0.95, 0.9, 0.9, 0.95, 0.9 and the certain factor of all rule is μ=0.90. Therefore the value of place;
p_{11} is max (min (μ_1, CB_{10}), min (R_3, CB_3)) = max (min (0.90, 0.90), min (0.90, 0.95)) = 0.90,
p_{12} is max (min (μ_2, CB_3), min (R_{10}, CB_{10})) = max (min (0.90, 0.95), min (0.95, 0.90)) = 0.90,
p_{13} is max (min (μ_3, CB_6), min (R_3, CB_3)) = max (min (0.90, 0.95), min (0.90, 0.95)) = 0.90,
p_{14} is max (min (μ_4, CB_5), min (R_{10}, CB_{10})) = max (min (0.90, 0.90), min (0.95, 0.90)) = 0.90,
p_{15} is max (min (μ_5, CB_{12}), min (R_{10}, CB_{10})) = max (min (0.95, 0.90), min (0.95, 0.90)) = 0.90.
We have $p_{16} = p_{17} = p_{18} = p_{19}$ = min (0.90, 0.90, 0.90, 0.90, 0.90) = 0.90. Eventually, the value in place p_{20} is 0.90. The probability of the fault occurs in Line 3 is 0.90. The diagnosis processes of the other transmission line models are similar and the computing process time is the same. Therefore we no longer go into details here.

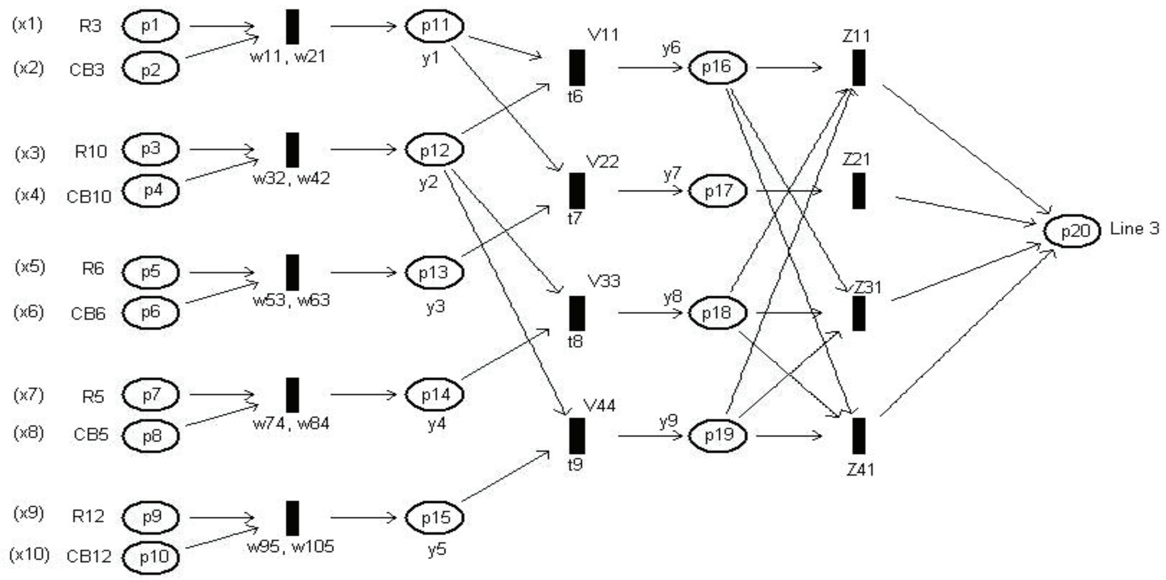

Fig.5. The FPN model for fault diagnosis of Line 3

Case studies

A part of an electric power system used for testing in figure 4. The tripping of protective relays is affected by diverse uncertain factors, and the alarm information from system is also incomplete.
Case 1: Operated relay R_1, R_5 and tripped CB_1, CB_5 are detected with the first truth value is 0.80, 0.70, 0.90, 0.80 consecutively. It is presumed that the certain values of all transition are 0.95. Result: Line 1 is faulted, and its truth value is 0.85.
Case 2: Operated relay R_2, R_{12} and tripped CB_2, CB_{12} are detected with the first truth value is 0.90, 0.80, 0.70, 0.80 consecutively. It is presumed that the certain values of all transition are 0.90. Result: Line 2 is faulted, and its truth value is 0.90.
Case 3: Operated relay R_3, R_{10} and tripped CB_3, CB_{10} are detected with the first truth value is 0.90, 0.90, 0.90, 0.90 consecutively. It is presumed that the certain values of all transition are 0.90. Result: Line 3 is faulted, and its truth value is 0.90.
Case 4: Operated relay R_4, R_7 and tripped CB_4, CB_7 are detected with the first truth value is 0.90, 0.70, 0.90, 0.80 consecutively. It is presumed that the certain values of all transition are 0.95. Result: Line 4 is faulted, and its truth value is 0.95.
Case 5: Operated relay R_6, R_{11} and tripped CB_6, CB_{11} are detected with the first truth value is 0.80, 0.80, 0.80, 0.70 consecutively. It is presumed that the certain values of all transition are 0.85. Result: Line 5 is faulted, and its truth value is 0.85.
Case 6: Operated relay R_8, R_{17} and tripped CB_8, CB_{17} are detected with the first truth value is 0.80, 0.90, 0.70, 0.70 consecutively. It is presumed that the certain values of all transition are 0.80. Result: Line 6 is faulted, and its truth value is 0.90.
Case 7: Operated relay R_9, R_{13} and tripped CB_9, CB_{13} are detected with the first truth value is 0.70, 0.90, 0.80,

0.80 consecutively. It is presumed that the certain values of all transition are 0.85. Result: Line 7 is faulted, and its truth value is 0.95.

Case 8: Operated relay R_{14}, R_{15} and tripped CB_{14}, CB_{15} are detected with the first truth value is 0.90, 0.90, 0.80, 0.90 consecutively. It is presumed that the certain values of all transition are 0.95. Result: Line 8 is faulted, and its truth value is 0.95.

Case 9: Operated relay R_{16}, R_{18} and tripped CB_{16}, CB_{18} are detected with the first truth value is 0.90, 0.90, 0.70, 0.80 consecutively. It is presumed that the certain values of all transition are 0.85. Result: Line 9 is faulted, and its truth value is 0.90.

Case 10: Operated relay R_3, R_{10}, R_8, R_{17} and tripped CB_3, CB_{10}, CB_8, CB_{17} are detected with the first truth value is 0.80, 0.80, 0.70, 0.90 consecutively 0.80, 0.95, 0.90, 0.85, 0.80, 0.95, 0.80, 0.90. Result: Line 3 and Line 6 are faulted and their value 0.85, 0.80, consecutively.

Case 11: Operated relay R_2, R_{12}, R_9, R_{13} and tripped CB_2, CB_{12}, CB_9, CB_{13} are detected with the first truth value is 0.80, 0.75, 0.85, 0.90 consecutively 0.85, 0.80, 0.90, 0.80, 0.85, 0.75, 0.85, 0.80. Result: Line 2 and Line 7 are faulted and their value 0.80, 0.75, consecutively.

Case 12: Operated relay R_6, R_{11}, R_2, R_{12}, R_8, R_{17}, R_{14}, R_{15} and tripped CB_6, CB_{11}, CB_2, CB_{12}, CB_8, CB_{17}, CB_{14}, CB_{15} are detected with the first truth value is 0.75, 0.85, 0.90, 0.95, 0.85, 0.90, 0.95, 0.85 consecutively 0.85, 0.80, 0.75, 0.90, 0.85, 0.90, 0.90, 0.80. It is presumed that the certain values of all transition are 0.85. Result: Line 5, Line 2, Line 6, Line 8 are faulted and their value 0.80, 0.75, 0.85, 0.85 consecutively.

Conclusion

Considering the several likely topologies and arrangements of the power system, the use of FPN is an adequate tool for the development of fault diagnosis system. This work develops a fuzzy model for power systems in order to be able to rapidly perform fault diagnosis. This approach has a practical significance and provides the possibility of hierarchically monitoring of power system. Though many methods are applied to the fault diagnosis, some current interests are basically focused on how to accomplish incompleteness and uncertainty of relay and circuit breaker that greatly influence of fault diagnosis.

The advantage of this model is that, it uses less number of parameters. Therefore it decreases the overall computational complexity of the model. For the FPN model we used the max-min rule, thus the outputs are excessively simple computed. Diagnosis only takes a few seconds to complete. Consequently, the result of fault diagnosis can be used for online control in power system.

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