The Fault Detection Model of Electric Power Systems Using Systematic Stochastic Petri Nets

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Abstract:

This paper proposes the modeling of electric transmission power network protection system using Systematic Stochastic Petri Nets (SSPNs). SSPNs, which own the perfect ability of modeling, are used in order to found electric power system faults detection model. Commonly, in substation function, when the electric power system declines, much of switch act data, fault data and alarm data will be carry over from the protection devices to the Supervisory Control and Data Acquisition (SCADA) system, most of them are right while some of them maybe wrong. It is a difficult objective for the operator in order to select the wrong one amidst so much data. Fault detection model is come up with in order to decide this problem. The major aim of substation fault detection model is using those data in order to get the right detection result of the fault zone. By the virtue of the substation fault detection, the operator briskly understands the important data and takes correct actions in time. The result of simulation indicates that the scheme has good performance in real time substation fault detection.

Key words: Fault Detection, Protection System, Electric Transmission Power Network, SSPNs

1. Introduction

Fault detection of electric power system is a process of discriminating faulted system components by tripping of protective relays and circuit breakers. Conventionally, fault detection in substation is done by human operator, it is crucial for dispatchers to briskly prediction the fault section in substation before starting restorative actions via the Supervisory Control and Data Acquisition (SCADA) data by their experience. In this circumstance, it is rather difficult to detect fault briskly and exactly merely by human operator with their experience. So as to distribute the fault detection result briskly, obviously and exactly. There are many methods, such as artificial neural networks, genetic algorithms, tabu search, logic reasoning and expert system, [1-2] which have been enforced to fault detection of electric power system. While using these artificial intelligence technologies in order to detect the substation faults, errors are commonly run across in their fault detection process [3-4]. Since these models do not represent the change of the substation configuration, or could not identify the error of the input signal, or needing much of training.

Systematic Stochastic Petri Nets (SSPNs) are a flexible, visualized graphical mathematical modeling tool able to do modeling many systems, particularly discrete event system [5]. They can be enforced to many aspects of electric power system. Much as electric power systems are continuous time systems from a macro power transmission approach, some operating procedures, such as contingencies associated with system change from one state to another state, switch action or relay can be viewed as a set of discrete events. Hence, the systems are made up of those procedures can be considered as discrete event systems, such as switching sequence action and

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protection system, from a micro operating approach. In substation, when a fault happened, associated circuit breakers and switches are tripped, it is a typical discrete dynamic process, and SSPNs have been used in fulfilling fault detection. SSPNs are powerful for real time detection by virtue of its obvious graphical models. Providing a good model is a significant and central task. In this paper, a SSPNs model is suggested based on paper [6] in order to carry out substation fault detection. The suggested fault detection method is carried out using the information of circuit breakers and protective relays. After they have reach their final state, and the fault section can be detected from the fired SSPNs of its final state. The detection process is very fast and simple.

2. Modeling Method of SSPNs

2.1. SSPNs definition

SSPNs are a one of several mathematical and graphical representations of discrete distributed systems. As a modeling language, it graphically depicts the structure of a distributed system as a directed bipartite graph.

The SSPNs are a directed graph; C = (P, T, I, O, M_0) where [7];

P = {p_1, p_2, ….., p_m} is a finite set of places,

T = {t_1, t_2, ….., t_m} is a finite set of transitions, $P \cup T \neq \emptyset$, and $P \cap T = \emptyset$;

I = (P X T) → N is an input function that defines directed arcs from places to transitions, where N is a set of non negation integers;

O = (P X T) → N is an output function that defines directed arcs from transitions to places,

M_0 = P → N is the initial marking.

2.2. Graphical model of SSPNs

The graphical model of SSPNs consists of nodes and arcs that represent different physical concepts. The node set is composed of two independent subsets, place set P = {p_1, p_2, …., p_n}, and transition set T = {t_1, t_2, …, tn}. Each node corresponds to only one place element p_i or transition element t_i. Two different kinds of weighted directional arcs are included in arc set, which are named as the subset of input arcs and the one of output arcs. The token number of each place is marked by a figure of dots in each place circle, which may not only represent a certain material resource but also denote some corresponding information resource [8].

The arc weight is marked with a figure and its default value is one. Figure 1 shows a simple SSPNs structure where p_1 and p_2 represent places and t_1 represents transition, and the dot in place p_1 represents the initial marking (token). The structures of SSPNs are static, and its dynamic properties are defined by transitions firing as well as transition of the tokens. The firing will move the tokens from the transitions input places to its output places [9].

Figure 1. Simple SSPNs structure

2.3. Matrix representation of SSPNs

Defining two matrices D^{-} and D^{+} representing input and output functions is alternative to defining a SSPNs as (P, T, I, O, M_0). Each matrix has *m* rows (two per transition) and *n* columns (one per place). D^{-} defines transition inputs, D^{+} defines transition outputs. The matrix form to define SSPNs; (P, T, D^{-}, D^{+}, M_0) allows giving definitions in terms of vectors and matrices [7]. Let us define a single vector *e[j]* of dimension *m* containing zeros in all places but the one corresponding to the transition being started at the moment. Apparently, the transition is permitted if $\mu \geq e[j] \bullet D^{-}$, the result of the startup of the j-th transition can be described as follows $\mu' = \mu + e[j] \bullet D$, and where $D = (D^{+} - D^{-})$ is the incidence matrix.

2.4. A simple fault detection of SSPNs model for substation

Figure 2 indicates a purified substation network. There are two outgoing feeders, N_1 and N_2, just observe feeder N_1, when a fault happened at node N_1, the main protection R_1 and circuit breaker CB_1 employs in order to clear the fault. If CB_1 failed to employ, the first backup protection R_2, R_3 and circuit breaker CB_2, CB_3 will employ in order to clear the fault. If CB_2 or CB_3 fails to clear the fault, the second backup protection and its corresponding circuit breakers will employ.

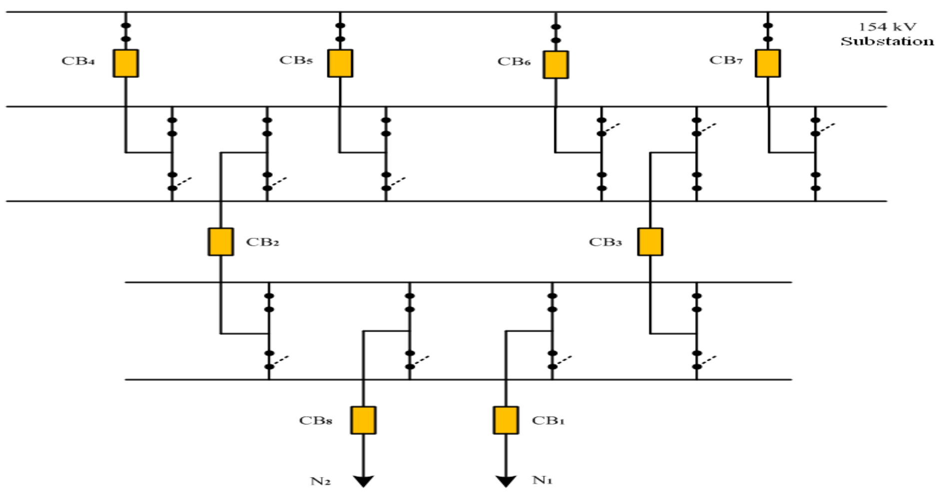

Figure 2. Purified substation network

So far as the aloft rules of protection configurations, the SSPNs model of the net for fault detection is indicated in figure 3. In this model, observe node N_1, place R_1, CB_1 present the main protection and its circuit breakers action state. Place R_2, R_3, CB_2, CB_3 present the primary backup protection and its circuit breakers action state. By the same, place R_4, R_5, R_6, R_7, CB_4, CB_5, CB_6, and CB_7 present the secondary backup protection and its circuit breakers action state. Place B_1, B_2, C_1, C_2, C_3 and C_4 are virtual nodes and have no physical meaning. In this model, the incipient token distribution is verified with respect to the information received from the control center and SCADA system. If the information illustrates that the relay R_n (R_1, R_2, R_3, R_4, R_5, R_6 and R_7) and circuit breakers CB_n (CB_1, CB_2, CB_3, CB_4, CB_5, CB_6 and CB_7) has employed, then there will be an incipient token set in corresponding place.

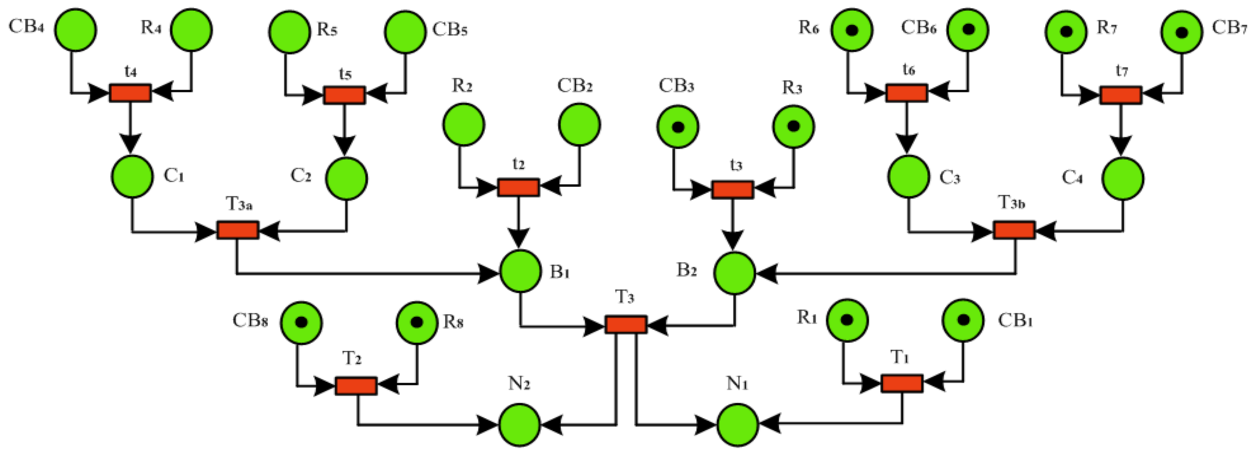

Figure 3. SSPNs model for purified substation network

After finishing incipient token distribution, the transition matching the circumstance will be fired. The firing circumstance of each transition is defined as follows [2];
If there is a token in both place CB_n and place R_n, transition tr_n (n = 2, 3, 4, 5, 6, 7) will be fired. If there is a token in each of place R_1 and CB_1, B_1 and B_2, C_1 and C_2, C_3 and C_4 respectively, transition T_1, T_2, T_{3a} and T_{3b} will be fired. The token will redeliver in the net after a series firing of transition until no transition can be fired, and then the net arrives the stable status. The fault section can be forthrightly derived from the net at that time. The measure rule is as follows; if there are tokens in place N, then node N is fault section.

3. Fault Detection Methodology

3.1. Detection procedure

At modeling in SSPNs, places denote certain system states, while transitions denote actions taking place in the system. The system may generate certain actions being in a certain state; and, vice versa, execution of a certain action shifts the system from one state to another. The current system state is defined by the SSPNs marking, the location of marks in the net places. Execution of actions in the system is defined as transition actuations in SSPNs. Actuation of transitions generates new marking, thus, generating new location of marks in the net.

The SSPNs shown in Figure 3 has a complex structure due to the existing parallel processes. In such cases, decomposition of the SSPNs are expedient, since the parallelism conditions increase in the number of system states in geometric progression accompanied by the increase of positions of each branch. Decomposition ensures decrease the number and complexity of synthesized logical sequences and more efficient realization of the sequences in distributed systems. When using decomposition, each branch is treated as a separate subnet. Decomposition results in a set of subnets and a net coordinating the starting of the subnets. The SSPNs decomposition in the automated control system of fault detects will result in functional subnets of the initial SSPNs as shown in Figure 4.

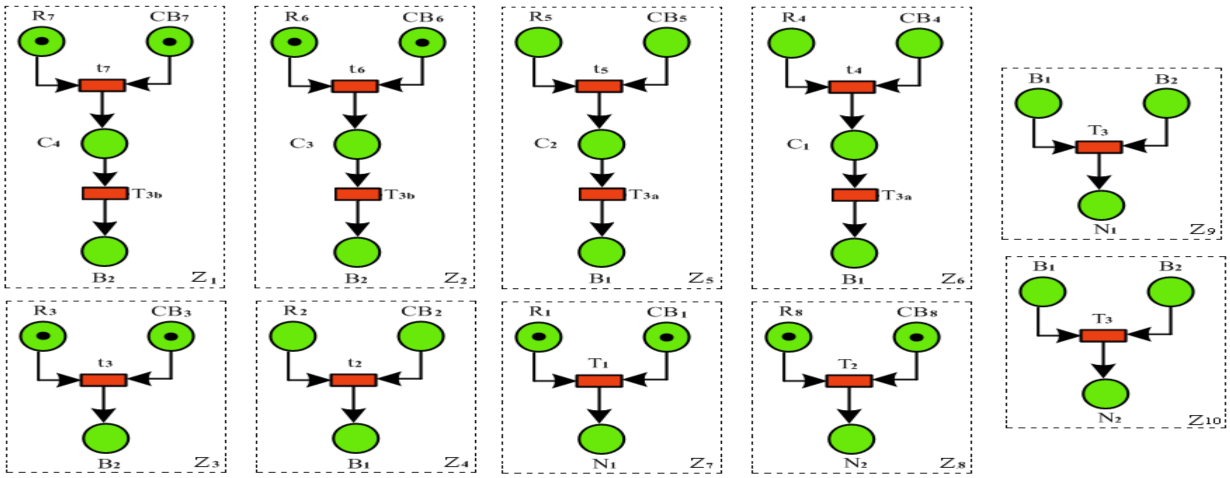

Figure 4. Functional subnets of initial SSPNs model

Let us perform the matrix analysis the subnets $Z_1 \rightarrow Z_{10}$. The subnet Z_1, as shown in figure 4, has 4 states (R_7, CB_7, C_4, B_2) and 2 transition (t_7, T_{3b}). Let us plot the matrix of inputs, the matrix of outputs and the incidence matrix for the subnets $Z_1 \rightarrow Z_{10}$.

$$Z_1 = D^-_1 - D^+_1 \rightarrow \quad D^-_1 = \begin{bmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}; \quad D^+_1 = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 \end{bmatrix}; \rightarrow \quad Z_1 = \begin{bmatrix} 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & 1 \end{bmatrix};$$

$$Z_2 = Z_1 \rightarrow Z_2 = \begin{bmatrix} 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & 1 \end{bmatrix};$$

$$Z_3 = D^-_3 - D^+_3 \rightarrow \quad D^-_3 = \begin{bmatrix} 0 & 1 & 1 \end{bmatrix}; \quad D^+_1 = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix}; \rightarrow \quad Z_3 = \begin{bmatrix} 1 & -1 & -1 \end{bmatrix};$$

$$Z_4 = D^-_4 - D^+_4 \rightarrow \quad D^-_4 = \begin{bmatrix} 0 & 0 & 0 \end{bmatrix}; \quad D^+_4 = \begin{bmatrix} 1 & 1 & 1 \end{bmatrix}; \rightarrow \quad Z_4 = \begin{bmatrix} 1 & 1 & 1 \end{bmatrix};$$

$$Z_5 = D^-_5 - D^+_5 \rightarrow \quad D^-_5 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}; \quad D^+_5 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix}; \rightarrow \quad Z_5 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix};$$

$$Z_6 = Z_5 \rightarrow Z_6 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix}; \quad Z_7 = Z_8 = Z_3 \rightarrow Z_7 = \begin{bmatrix} 1 & -1 & -1 \end{bmatrix}; \quad Z_8 = \begin{bmatrix} 1 & -1 & -1 \end{bmatrix};$$

$$Z_9 = Z_{10} = Z_4 \rightarrow Z_9 = \begin{bmatrix} 1 & 1 & 1 \end{bmatrix}; \quad Z_{10} = \begin{bmatrix} 1 & 1 & 1 \end{bmatrix};$$

The matrix analysis method ensures vivid demonstration of the application of mathematical apparatus in describing internal logical operations of the fault detection model of electric power systems.

3.2. Detection result analysis

After three times firing of the transition, the net arrives its final stable status. In the final SSPNs model, there is a token in place R_1, R_2, N_1 respectively. So far as the measure rules of the fault detection, a token in place N_1 means the node N_1 exist fault. Therefore a conclusion can be drawn that node N_1 is the fault area. The fault is purged by the primary backup protection R_3, circuit breaker CB_3 and the secondary backup protection R_4, R_5, circuit breaker CB_4, CB_5. As a token in place R_1 and R_2 shows that R_1 and R_2 have employed, but their corresponding circuit breakers CB_1, CB_2 have not employed. Therefore the transition T_1 and t_2 has not fired and the token in R_1 and R_2 has not moved and yet in their place. CB_1 is rejected to act, and the secondary protection must be started. No token in secondary protection R_3 and CB_3 indicates that CB_3 has employed to clear the fault. While R_3, CB_3 employed, R_2, CB_2 also should employ as the same level protection. But CB_2 failed in order to employ, so it's corresponding lower level protection and circuit breaker CB_4, CB_5 employed in place of CB_2 in order to clear the fault.

Conclusions

The operators of power station control room need to a system to aid and support them to make reasonable decisions during critical situations and reducing the delay of restoration after emergency, a purified SSPNs fault detection system is proposed to deal with a lot of alarms and tripping signals which are sent to the power station control room. The paper proposes a fault detection system based on SSPNs for an electric power system, which includes; load units, power transformers, block bus and station buses. The proposed method can be applied on electric power station through building SSPNs model for each section. Moreover, it can deal with disoperation of the circuit breakers. The proposed method is tested on electric power system to demonstrate its performance and effective. The testing results demonstrate that proposed method is easy reasoning method, effectiveness and strong practicability of fault detection methods to actual electric power systems. The detection results can be easily drawn from the final stable SSPNs model rather than further reasoning. So, SSPNs model is excellent for substation fault detection.

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