Fault Diagnosis Knowledge Reasoning of Switching Network in Distributed Generation Based on Petri Net

Ziquan Liu[1], Xueqiong Zhu[1], Jingtan Ma[1], Hui Fu[2], Ke Zhao[1] and Chengbo Hu[1,*]

[1]*Electric Power Research Institute of State Grid Jiangsu Electric Power Co., Ltd, Nanjing, 210000, China*
[2]*State Grid Jiangsu Electric Power Co., Ltd, Nanjing, 210000, China*
E-mail: 26525729@qq.com; 18795897606@163.com; jingtanma@126.com; fuhui@js.sgcc.com.cn; 15105168884@163.com; huchengbo01@163.com
[*]*Corresponding Author*

Received 06 August 2021; Accepted 17 August 2021;
Publication 09 November 2021

Abstract

Telephone network based on IMS technology has been widely applied in power production and dispatching communication, especially in distributed power stations. Analysis and positioning failure of IMS network is arduous, because it's dependent on IP data communication network. In this paper, we first introduced IMS switching network architecture and distributed generation communication network architecture, analyzed and summarized all kinds of network malfunction. Combining typical IMS network fault connection relations, we introduced an improved Petri net fault handling model and reasoning method. The diagnosis and positioning results could reflect the defects of equipment logic functions. This method on fault diagnosis and location of substation network has been proved to be effective through practical application.

Keywords: Knowledge reasoning, distributed generation, Petri net, fault diagnosis.

Distributed Generation & Alternative Energy Journal, Vol. 37_2, 341–360.
doi: 10.13052/dgaej2156-3306.37213

1 Introduction

With the development of communication technology, the distributed generation dispatching communication began to develop from program control switching technology to IMS technology. Video conference, IP telephony, office automation system and other broadband integrated services have been continuously developed, in order to meet the needs of the telephone, video, data and other multimedia fusion communication services in power production, which provides rich multimedia communication services for power production. IMS switched network adopts IP data communication as the bearer network, and includes several network elements such as C/P/I-CSCF, HSS, ENUM, MGCF, etc., making the fault points and fault factors of IMS switched network increase a lot compared with the original circuit switched network. IMS network failure involves not only the bearer network and device network element, but also the configuration of service data and business logic. The breakdown of the network and equipment can access the reasoning of the warning information or field condition, but the business data error and the complex logical relationship fault is difficult to obtain through the reasoning. Therefore, distributed generation needs a fault diagnosis method for equipment link and logic layer information missing and error.

Petri net is a kind of working model which can describe the asynchronous concurrent operation of the system. It can describe the internal parallel process and logical relationship of the system from the perspective of the process. Based on the information characteristics and network structure of IMS network in the case of fault, this paper proposes a fault diagnosis and location model based on Petri net, which can diagnose and locate the fault of network equipment, link on-off and service logic [1–6].

2 Fault Analysis of Substation Switching Network

2.1 Substation IMS Switching Network Architecture

IMS switching network used for distributed generation dispatching communication mainly consists of core network and access network. IMS core network is composed of two sets of systems, in accordance with the requirements of disaster tolerance in different places. The main system is deployed in the computer room of the main node of the data communication network, with 2 provider edge routers (PE device). The backup system is deployed in second convergence point machine room with 1 provider edge router. Each device is separately connected to the backbone of the data communication network.

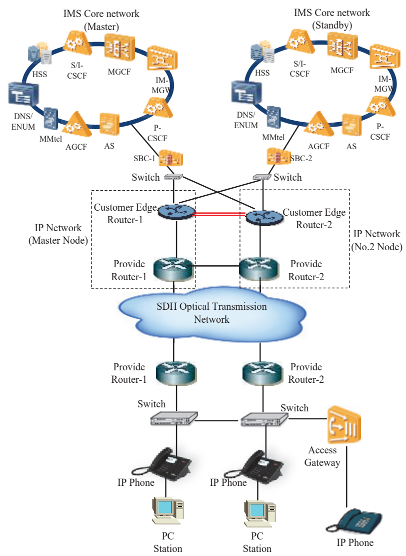

Figure 1 Communication network structure in distributed generation.

Each IMS system is equipped with two networking switches. One switch aggregates the primary ports of all IMS devices, and the other aggregates the standby ports of all IMS devices. For IMS access network, communication terminal (such as SIP phone, etc.) is directly connected to the AG device through existing switch equipment, and then connected to the IMS core network through the sink switch. The IMS network networking architecture is shown in Figure 1.

2.2 Network Structure

1. IMS core network

IMS (IP Multimedia Subsystem, IMS) technology is proposed by 3GPP International Standardization Organization, which is a general network architecture that provides multimedia services on IP-based networks. It defines the core structure, network element functions, communication interfaces and business processes of IMS system.

IMS technology further separates network Control, which realizes the separation of session control entity CSCF (Call Session Control Function, CSCF) and media control entity MGCF (Media Gateway Control Function, MGCF), and makes the communication network architecture more open and flexible. Figure 2 shows the IMS network structure.

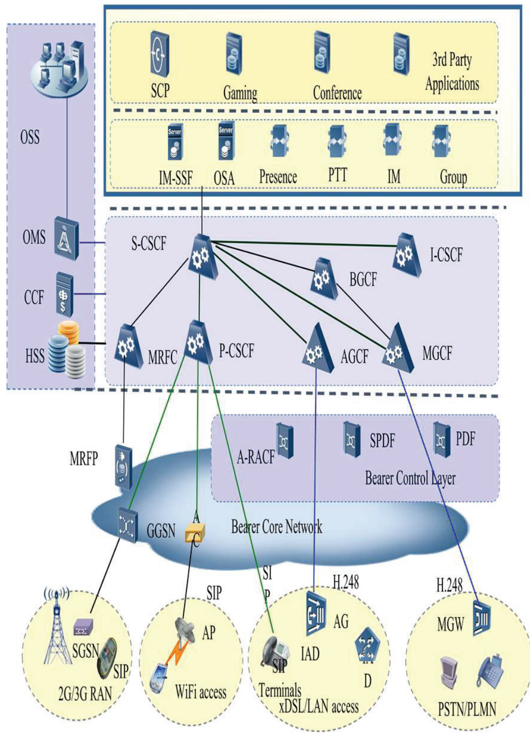

Figure 2 The IMS network structure.

In the IMS network structure, the lowest layer is the terminal access layer, which is used to provide terminal access and data transmission. It adopts packet switching based IP data network.

The middle layer is the core control layer, which is responsible for managing the setting, modification and release of calls and sessions, and completes the signaling control of all IP multimedia services by it. The main functional entities of core control include CSCF, HSS, MGCF, etc. These network elements perform different roles, such as signaling control server, database, media gateway server, etc., and cooperate to complete signaling level processing functions, such as SIP session establishment and release. This layer is only responsible for IMS signaling, and the media stream does not pass through this layer.

The top layer is the application layer, which is composed of application and content servers and is responsible for providing IMS services to users. The main network element is a series of application platforms that provide multimedia services through CAMEL, OSA/ PARLAY and SIP technologies. All the services in IMS system, including the traditional concept of telephone, fax, etc. are realized by various service servers, and the core control layer only triggers the services according to the initial filtering rules. Users can develop their own SIP based applications that connect to IMS systems through standard SIP interfaces. If third-party applications need to be connected, IMS can manage third-party services using standard API interfaces.

Open interface protocol is used between different functional areas of IMS network, which has the control ability and service provision ability of multimedia session service based on IP network and SIP protocol. Among the network elements of IMS network, SIP protocol is used for communication between CSCF and MGCF network elements. In contrast, Diameter protocol is used for communication between CSCF and HSS network elements. IMS network can use ISUP protocol and MGCF/MGW equipment to communicate with existing switching network or telecom operator network, and can also communicate with soft switching network or public IMS network through SIP-I protocol.

2. IMS access network

IMS access network mainly realizes the integrated access for terminal, AG and IAD devices. In the access network, business terminals are connected to two switches via AG devices, which can protect the transmission channel, but it increases the probability of network failure at the same time. In terms of transmission channel, considering the short transmission distance of Ethernet, optical fiber transmission should be preferred. AG equipment is generally deployed in the machine room and directly connected to the sink switch using VRRP protocol to realize the protection of redundant channels. Figure 3 shows the IMS access network structure.

2.3 Problems in Fault Analysis

The fault of IMS switching network in substation is mainly divided into three categories. The first is equipment hardware failure, such as equipment board card failure, port failure, host failure, etc. The second is communication link failure, such as PRA, No.7, SIP signaling link failure, etc. The third is abnormal performance, such as abnormal initial registration success rate of SBC equipment, abnormal CSCF access rate, etc. The fault is also a variety of forms, such as telephone obstruction, number display error; equipment cannot log in, call interruption, etc. Fault trouble shooting relies on manual

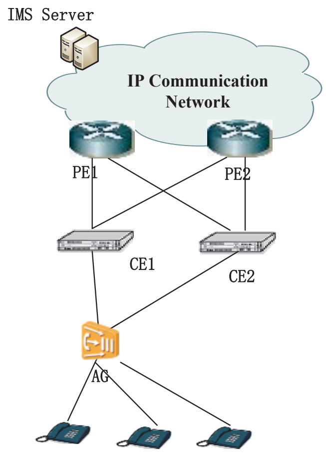

Figure 3 IMS access network structure.

experience and with the help of alarm analysis, performance index positioning, message tracking, bearer network fault analysis, to determine fault network elements and fault causes, identify fault points and evaluate impact areas.

The fault handling process of IMS switched network is a complex of dynamic, multivariate, nonlinear event with a large amount of data. It is difficult to find a suitable data model to fully express the fault at present. At the same time, when a failure occurs, it's a matter of seconds to recover from some failures, such as power production telephone, dispatching telephone, etc. In addition, the mental pressure of maintenance personnel is very large. Especially when complex and scale faults occur, it is impossible to achieve the requirements of rapid recovery only by relying on manual experience, and there are risks of errors and mis-operation that lead to expansion or delay of faults [7–9]. This paper attempts to use Petri net analysis method to analyze business system faults and obtain fault processing steps, and then designs IMS service fault diagnosis system based on Petri net knowledge reasoning to assist operation and maintenance personnel in fault processing.

3 Petri Net Model of Communication Network Fault

3.1 Traditional Petri Net Diagnostic Model

Petri net is a kind of system model suitable for describing asynchronous concurrency phenomenon. It has both strict mathematical definition and intuitive

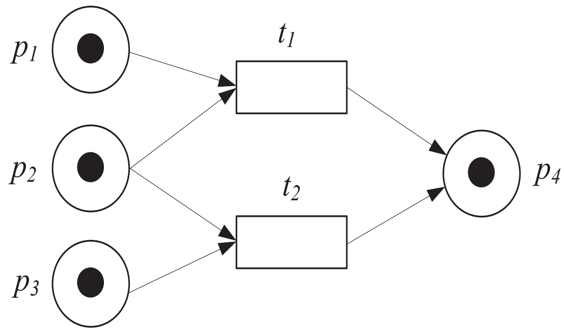

Figure 4 Fault propagation model of Petri net.

graphic representation, which is suitable for people's thinking and cognition of objective events. Petri net is an effective method to deal with events of discrete resource flow. The intuitive graphical way makes the reasoning process of Petri clearer. The simple matrix operation can identify and locate faults quickly, accurately and stably.

Traditional Petri net describes the flow process of resources. The occurrence of transition ignition events, token flows towards an arc from the changing input place to the changing output place, and then Token disappears in the changing input Place, which shows that the resources in Petri nets are not reusable and coverable, so it is not suitable for network fault propagation. The fault propagation model represented by Petri nets is indicated in Figure 4 Circles represent the library and the system status or fault information; the black dots in the circle represent the number of Token resources in the library; the rectangular box represents transition; transition ignition represents the occurrence of transition events [10, 11].

According to the traditional theory of Petri, there is resource competition conflict at p2 and resource collision atp4 in failure propagation model of Figure 3. However, there is concurrency in the process of fault propagation, such as multi-cause one effect, multi-cause many effects and multi-cause many effects. Multiple fault information eventually converges to the central equipment along multiple propagation paths to break down. In the traditional Petri net, transition ignition occurs and consumes Token of the change input place. According to this fault event description, it means that the fault of the fault source will disappear after the fault propagation occurs, which is inconsistent with the fact of fault propagation. Therefore, the traditional Petri net cannot objectively describe the actual fault propagation characteristics, and will be modified to describe the actual fault propagation characteristics.

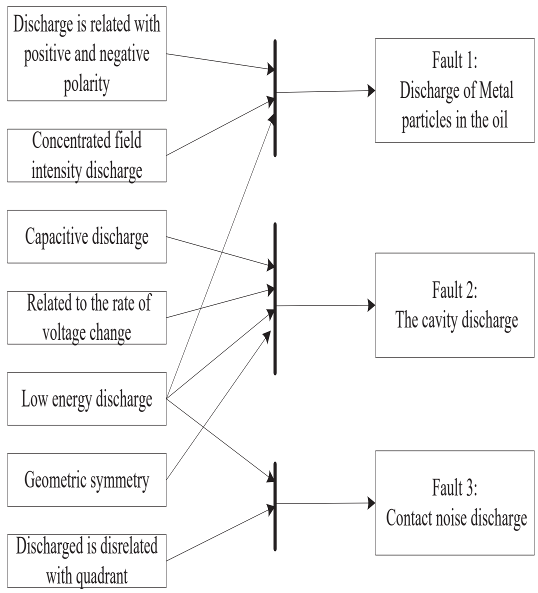

Figure 5 Knowledge expression of transformer fault diagnosis system.

According to the above rules, taking transformer fault diagnosis system as example, expert logic knowledge can be transformed into the following Petri network model for expression as the Figure 5.

3.2 Improved Model

In the improved Petri network fault diagnosis model, token in the input database before the transition will not disappear due to the occurrence of transition events, and there is no resource conflict and collision problem. Transition ignition in Petri net is no longer the flow of resources, but the multiplication and derivation of fault information [12, 13]. Fault information can be transmitted along multiple paths, either “horizontal” or “vertical”, and can be superimposed on each other to produce more serious faults, in line with the fact of fault diagnosis.

Definition 1. Petri net fault diagnosis model definition.

Let Σ =(P,T,F,K,W,S,M0,I,O) be a 9-tuple directed network, where:

(1) P={p1,p2,...,pn} is a set of non-empty finite libraries;
(2) T={t1,t2,...,tn} is a non-empty finite transition set, indicating the occurrence of fault events;

(3) F is a connection, represents a directed relationship from place to transition (or a vector relationship), F$\subseteq$(P$\times$T)$\cup$(T$\times$P)($\times$ is Cartesian product), dom(F)$\cup$cod(F)=P$\cup$T, there in:

$$\mathrm{dom(F)} = \{\mathrm{x}|\exists \mathrm{y} : (\mathrm{x}, \mathrm{y}) \in \mathrm{F}\}, \quad \mathrm{cod(F)} = \{\mathrm{y}|\exists \mathrm{x} : (\mathrm{x}, \mathrm{y}) \in \mathrm{F}\},$$

are the domain and range of F, respectively.

(4) K is transition trigger vector, indicating whether the transition in T set enables, K: P$\rightarrow\{0,1\}$ is the capacity function of the fault Petri net;

(5) W is weight function on the arc. It is the relationship between the place and the transition, and describes the direction of the directed arc. Default value is $+1$, represents the transition from the place to the transition. Otherwise, default value is -1, represents the transition from the place to the transition;

(6) S is the set of path labels for recording transitions, and the initial set of the system is empty; Tk(n) represents transition Tk ignition at time k. After transition ignition, S=S+$\{$Tk(n)$\}$;

(7) M0 is the initial state of the system;

(8) I is the set of system input place;

(9) O is the set of system output place.

Definition 2. Petri net correlation matrices and equations of state.

Correlation matrix and equation of state are the most important tools for Petri net modeling and analysis. Traditional correlation matrix and state equation of Petri nets are not suitable for calculating transition ignition process of fault Petri nets. Therefore, it is necessary to redefine the correlation matrix and state equation of fault Petri net.

Correlation matrix

Let Σ =(P,T,F,K,W,S,M0,I,O) be a fault Petri net, P = $\{$p1,p2,...,pn$\}$, T = $\{$t1,t2,...,tm$\}$, n, m $\in$ z+, matrix C = [Cij] ($1 \leq$ i $\leq$ n, $1 \leq$ j $\leq$ m) is the correlation matrix of the Σ, where Cij = W(tj,pi).

Equations of state

Mk+1 = Mk+(CUk)

Where: Mk, Mk+1 is the initial representation set and the result representation set at the ignition of the K transition, respectively. C = [Cij]isn row m column matrix, Uk is the transition sequence at the time of k, which is the m $\times$ 1 matrix made up of 0, 1.

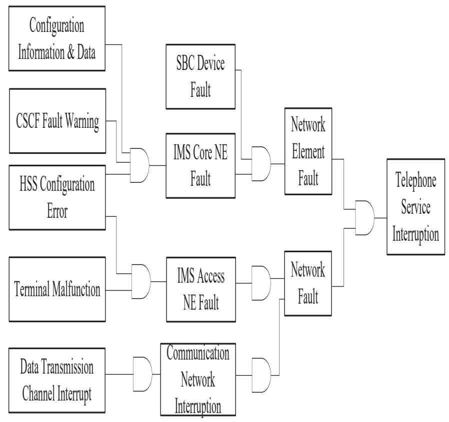

Figure 6 IMS fault connection tree.

3.3 Substation Communication Network Fault Tree Model

Considering the characteristics of IMS switched network system and service, the final manifestation of the fault is the service interruption, such as the inability to talk. The fault causes can be classified into two categories: core network fault and access network fault. Each type of fault can be caused by terminal equipment and network equipment. Combined with the IMS Switched Network networking architecture, the IMS service fault model example is shown in Figure 6.

The IMS fault model can be represented in the form of a fault connection tree T = (D,R), where D is a finite set of nodes, and R is a failure node. In the design of fault connection tree, first of all, the network breadth is searched in priority, and the directed connection relationship is formed. In a branch search, it terminates when a terminal or device node is found. Where Droot?D and has no precursor under the relation, Dleaf?D and has no successor under the relation. For the fault connection tree, the leaf node Dleaf has only two types: terminal and network device.

4 Fault Modeling Process and Diagnosis Algorithm of Petri Net

4.1 Petri Net Modeling

According to the definition of Petri net, the fault connection tree and protection object can be mapped to Petri net. The network device node of the tree is

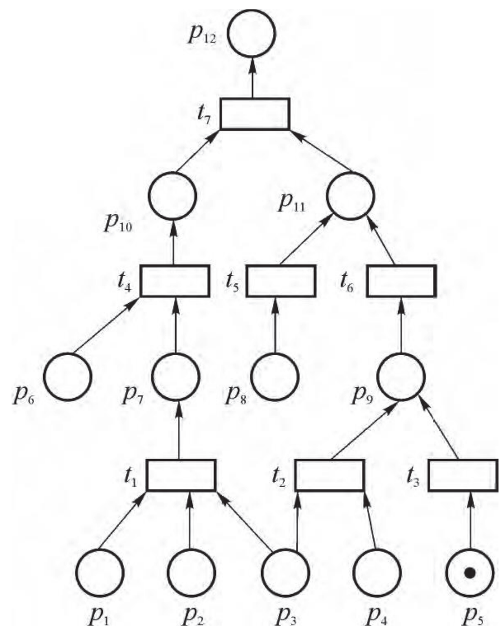

Figure 7 Petri net representation of network fault processing flow.

converted into a Petri net repository, and the remaining nodes are converted into the transition set of Petri net, leading to the fault tree direction consistent with the Petri net arc direction. During fault diagnosis, the object instantiated by specific service is encapsulated into Token form and put into the network device place. The fault handling flow in Figure 4 is transformed into the Petri net in Figure 7.

The data structure of Petri net is still tree structure after placing in Token, so pruning algorithm can be used to further optimize it. Starting from the node of the end place, the search moves forward towards the transition direction until the first network device library is accessed in Token. The Petri net branch accessed in this process plays no role in determining the fault network elements, so pruning processing can be done.

4.2 Fault Reasoning

Complete model should be established by combining the basic situation and parameter structure of Petri net, to ensure the rationality and integrity of fault analysis.

Firstly, forward simulation of failure. In the forward fault simulation process, based on the analysis of the key points of communication lines, network structure and network element composition shown in the library, the Token is used to analyze the working state of the specific structure, and the fault propagation is determined by the transition process analysis. At the same time, the arc suppression is used for signaling analysis to efficiently maintain the priority application of the service.

Secondly, the reverse fault diagnosis model is established. After deducing the specific fault occurrence mechanism, a complete Petri net model is established in combination with the actual situation. According to the requirements of network structure, the judgment efficiency of change direction is improved, and the logical reasoning level in fault diagnosis is described according to the logical relation control and processing basic model of Petri net description system, so as to form the Petri net fault diagnosis mechanism that meets the actual needs. The fault reasoning steps of Petri net are as follows:

(1) According to the historical operation data, expert experience knowledge and actual monitoring and collection data, the weights of each input position, the transferred confidence and threshold, the confidence of the initial position and the failure probability of the model are determined. Through the calculation of the confidence matrix f(x), the confidence P of the fault events in each position is deduced, and the necessary conditions are provided for the intelligent reasoning of the fault.
(2) Based on the confidence of each position and the fuzzy transfer rules, the potential enabling transfer sequence is calculated, which provides the basis for the subsequent intelligent reasoning ignition judgment.
(3) When there is no fault in the system, the online monitoring equipment is used to predict the possible fault symptoms in the communication network and determine the initial identification. Ignition transfer sequence judgment is used to carry out forward intelligent reasoning to the fault state, and the current network fault state is evaluated.
(4) When the system fails, the phenomenon of failure has been confirmed, and the reverse intelligence inferences the reverse position reachable sequence. The most likely fault source can be traced according to the fault correlation matrix, so as to provide guidance for the emergency repair of communication equipment. The reasoning process of Petri net is shown in Figure 8.

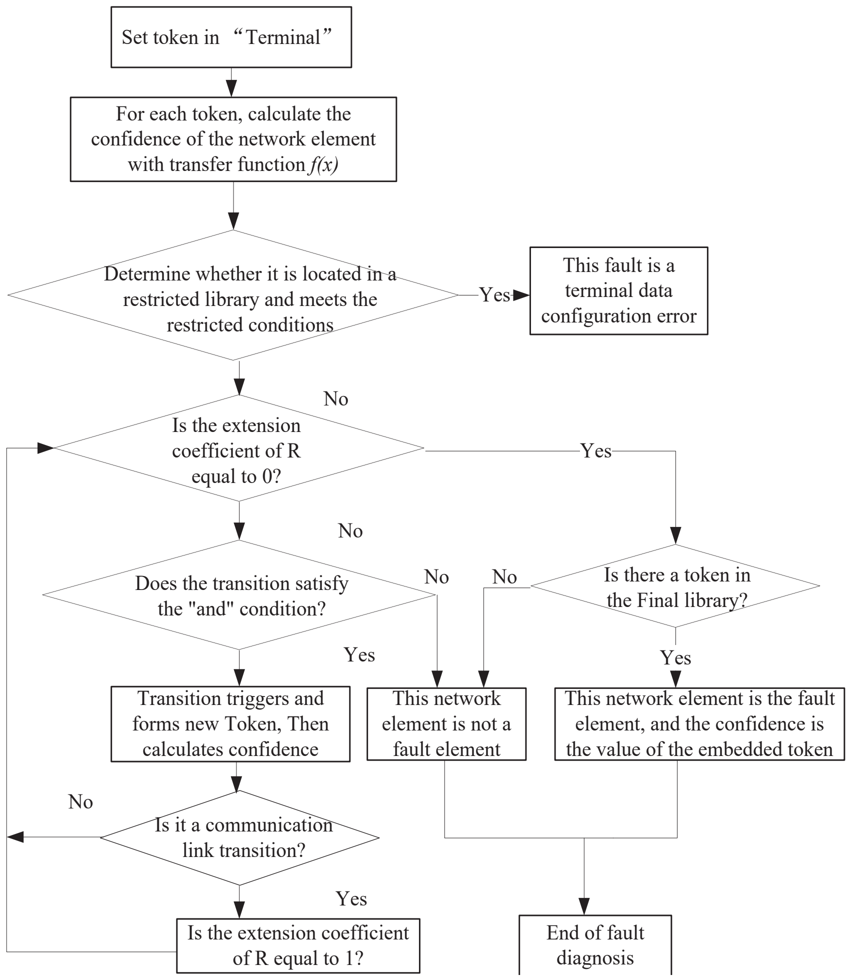

Figure 8 Reasoning process of Petri net fault diagnosis.

5 Petri Net Fault Diagnosis

5.1 Petri Net Fault Diagnosis Algorithm

The implementation of Petri nets is achieved by the ignition of transition, which marks a change in the state of the input and output places for that transition. Token is used to represent the state of the repository in Petri net and is represented as a black dot in the circle in the net diagram. As the transition is ignited, the position of the Token will also change until the final state.

Whether a transition ignites or not is determined by the transition triggering vector K, and K is determined by the relationship between the current Token value and the transition. If the value of K corresponding to the transition is greater than or equal to 1, the transition enables; otherwise, the transition is closed.

According to the above rules, the analysis steps can be drawn:

(1) Determine the initial identification of Petri net $M0 = cp \times 1$ as a matrix with p row and 1 column. The correlation matrix is $Ci \times j = W(tj,Pi)$ ($1 \leq i \leq n$, $1 \leq j \leq m$), and order $S = \Phi$, path label counter t=0, find the path in the path label set, label the change that has been performed, and do not repeat the change.
(2) Indicated by the initial state of M0, the transition sequence matrix of Uk at this time is written according to transition ignition rule conditions.
(3) After the transition ignition, according to the transition rule, a new state identifier Mk+1 is written from the state equation, and the transition path is added to S, and the counter t = t+1.
(4) If there are multiple paths, repeat step (3).
(5) Calculate the Token of the target place by the above steps. If the Token value of the target is greater than 0, it indicates that the fault has occurred; otherwise, no fault has occurred.

5.2 Example Analysis

In the fault diagnosis model in Figure 4, p1∼p8 are terminal node devices. p5 with black dot indicates failure, and p12 is the target node. According to the algorithm introduced above, for specific cases, the diagnosis process is as follows:

(1) Initial conditon M0 = [0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0] T, collection of transition path tags $S = \Phi$, counter t = 0.
(2) Find the association matrix in Figure 9.
(3) According to the case, transition t3 meets the ignition condition, and then the ignition transition sequence U1 = [0, 0, 1, 0, 0, 0, 0] T.
(4) After the transition t3 ignition, it is calculated from the state equation M1 = [0, 0, 0, 0, 1, 0, 0, 0, 1, 0, 0, 0] T, add t3 into S = {t3(0)}, t = t+1 = ‘1.
(5) Transition t6 satisfies ignition condition, ignition transition sequence is U2 = [0, 0, 0, 0, 0, 1, 0] T.

$$
C = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1
\end{bmatrix}
$$

Figure 9 Incidence matrix.

(6) Repeat step (4), M2 = [0, 0, 0, 0, 1, 0, 0, 0, 1, 0, 1, 0] T, transition t6 plus S = {t2(0),t6(1)}, t = t+1 = 2.
(7) Transition t7 satisfies ignition condition, ignition transition sequence is U3 = [0, 0, 0, 0, 0, 0, 1] T.
(8) Repeat step (4), M3 = [0, 0, 0, 0, 1, 0, 0, 0, 1, 0, 1, 1] T, transition path set S = {t2(0),t6(1), t7(2)}, t = t+1 = 3.

Above calculation and analysis are summarized by the final target status marker M3 = [0, 0, 0, 0, 1, 0, 0, 0, 1, 0, 1, 1] T, existence of Token in the target node indicates that the target node is bound to fail. Meanwhile, it can be known from the path set that the fault propagation path node is p5→p9→p11→p12. On the other hand, the information collected by the transition path can also be used for network fault warning. When device p5 has fault information, according to the strict formalized reasoning process of Petri net, device p9, p11, and p12 will inevitably have fault events. The status identification Mk clearly records the fault information in each state of the system, which is convenient for maintenance staff to quickly maintain the network.

6 Discussion

The faults of IMS switching network are caused by various factors, which not only involve equipment, data configuration, service processing process, but also involve network communication. In addition, the troubleshooting process is a very complex process. The Petri net analysis method proposed in this paper is accurate for the identification and processing of system faults and equipment faults in IMS network. The logical relationship between the Network elements in the IMS network is very close, but the relationship with the communication devices is not. The communication network fault may involve more network devices. Therefore, it is necessary to comprehensively analyze the status of the network devices to obtain effective reasoning. For the follow-up research, it needs to combine IMS network and communication network for analysis, so as to get more accurate reasoning and conclusion.

7 Conclusion

Taking the fault diagnosis of substation communication switching network as the research object, starting from the actual occurrence and propagation mechanism of the fault diagnosis of communication network, the fault diagnosis technology based on Petri net is put forward, the limitations of the traditional Petri net are analyzed, and the improved Petri net model algorithm is put forward, which provides a new solution for the fault diagnosis technology of network. An example shows that the proposed method can accurately diagnose and locate the faults of switching network equipment or terminals. This paper provides a new and innovative method for fault reasoning and diagnosis in IMS network.

The integrated access scheme of IMS network access device proposed in this paper can be applied in various access devices and application scenarios. It provides technical principles for the construction of IMS access network in electric power enterprises.

Acknowledgement

The work is supported by the State Grid Corporation of China (SGCC) project “Research and Application of Knowledge Navigation and Decision Optimization Technology Based on Artificial Intelligence” (No. 5200-201918255A-0-0-00).

Conflict of Interests

We all declare that we have no conflict of interest in this paper.

References

[1] WEI Lifeng, ZHANG Zhidong, YANG Yaqi. "The Application of Expert System in Dry-type Transformer Fault Diagnosis System," Shanxi Electric Power, vol. 178, issue 1, pp. 22–24, 2013.

[2] GUO Chuangxin, ZHU Chuanbai, CAO Yijia. "Researchstatus and development trend of power system fault diagnosis," Power System Automation, vol. 30, issue 8, pp. 98–103, 2006.

[3] JI Ligang, CHEN Hao, TAN Fenglei. "A model of fault diagnosis for power system based on time sequence fuzzy Petri net," Electric Power Engineering Technology, vol. 38, issue 9, pp. 93–99, 2019.

[4] PAN Zhixin, LIU Liguo, QIAN Cheng, WANG Zhen and YUAN Dong. "Pattern recognition of partial discharge based on fusion extreme learning machine,"Electric Power Engineering Technology, vol. 38, issue 5, pp. 42–48, 2019.

[5] LI Yongyong, ZHANG Yongjin, ZHANG Yanjun. "Design of Vehicle Fault Diagnosis Expert System Based on Petri Net," Mechanical Engineering & Automation, issue 1, 2020.

[6] LIU Wenze, ZHANG Jun, DENG Yan. "Transformer Fault Diagnosis Method Based on Deep Learning and Multi-dimensional Information Fusion," Electric Power Engineering Technology, vol. 38, issue 6, pp. 16–23, 2019.

[7] SUN Guoqiang, SHEN Peifeng, ZHAO Yang, ZHU Hongqin, DING Xiaoliu. "Intelligent recognition of power grid monitoring alarm event combining knowledge base and deep learning," Electric Power Automation Equipment, vol. 40, issue 4, pp. 40–47, 2020.

[8] WANG Lei, CHEN Qing, GAO Zhanju. "Representation and Application of Fault Diagnosis Knowledge in Power Transmission Grids," Proceedings of the CSEE, vo1. 32, issue 4, pp. 85–92, 2012.

[9] TU Min. "Application and Analysis of Petri Net Theory in Power Network Fault Diagnosis," Telecom Power Technology, vo1. 35, issue 12, pp. 100–101, 2018.

[10] CHEN Jun, LIU Xin, WANG Liping, ZHENG Zhong, YE Xiang, REN Jie. "Research on fault diagnosis and location method in smart

substation protection and control based on Petri net," China Measurement & Test, vo1. 45, issue 10, pp. 128–134, 2019.
[11] YU Hao, JIN Xin, SHI Jian, WEI Xunhu. "Research on Signaling Performance Analysis Method of IMS Administrative Switching Network Based on Petri Net," Computer & Digital Engineering, vol. 48, issue 6, pp. 1540–1544, 2020.
[12] XIE Min, WU Yaxiong, YAN Yuanyuan. "Powergrid fault diagnosis based on improved dynamic adaptive fuzzy Petri net and BP algorithm," Chinese Journal of Electrical Engineering, vol. 35, issue 12, pp. 3008–3017, 2015.
[13] LIU Xinrui, GAO Yiwei, WANG Zhiliang. "Distribution network fault diagnosis method based on improved timefuzzy Petri net," Journal of Northeast University (Natural Science Edition), vol. 37, issue 11, pp. 1526–1529, 2016.

Biographies

Ziquan Liu is an engineer of Electric Power Research Institute of State Grid Jiangsu Electric Power Co., Ltd. He received his Ph.D. degree of Huazhong University of Science and Technology. He studies in image recognition technology and power equipment status evaluation.

Xueqiong Zhu is an engineer of Electric Power Research Institute of State Grid Jiangsu Electric Power Co., Ltd. He received his Ph.D. degree of Southeast University (SEU). He studies in electric Internet of Things and Artificial Intelligence.

Jingtan Ma is an engineer of Electric Power Research Institute of State Grid Jiangsu Electric Power Co., Ltd. He received his Ph.D. degree of Xi'an Jiaotong University. He studies in research on state evaluation technology of switching equipment.

Hui Fu is an engineer of State Grid Jiangsu Electric Power Co., Ltd. She received her master degree of South China University of Technology (SCUT).She studies in power equipment condition evaluation.

Ke Zhao is an engineer of Electric Power Research Institute of State Grid Jiangsu Electric Power Co., Ltd. He received his master degree of Tsinghua University. He studies in switching equipment condition evaluation.

Chengbo Hu is a senior engineer of Electric Power Research Institute of State Grid Jiangsu Electric Power Co., Ltd. deputy director of Power Transmission and Transformation Technology Center as well as deputy director of Artificial Intelligence Laboratory of Power System of State Grid Corporation (Jiangsu).