ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2012. No. 2(118)
ELEKTRONIKA IR ELEKTROTECHNIKA

ELECTRICAL ENGINEERING
T 190
ELEKTROS INŽINERIJA

Modeling of Fault Diagnosis in Power Systems using Petri Nets

N. Pamuk
Turkish Electricity Transmission Company,
Sakarya, Turkey, phone: +90264 275 1030, e-mail: nihatpamuk@gmail.com
Y. Uyaroglu
Department of Electrical Electronics Engineering, Faculty of Engineering, Sakarya University,
Sakarya, Turkey, phone: +90264 2955814, e-mail: uyaroglu@sakarya.edu.tr

crossref http://dx.doi.org/10.5755/j01.eee.118.2.1175

Introduction

The modern power system is vitally significant for daily life. It is a large scale dynamic system. Fault diagnosis in power systems targets at identifying the faulted components in power systems based on the information of the current status of protective relays and circuit breakers available from Supervisory Control and Data Acquisition (SCADA) systems. It is known that online automatic fault diagnosis is vital to the restorative control and as a result of tremendous significance in declining power supply interruption and enhancing service reliability, particularly for the large size power system with large numbers of Intelligent Electronic Devices (IED) [1]. Fault diagnosis ought to be executed quickly and exactly so as to isolate the faulted components from the healthy part of the system and in order to take appropriate countermeasures to recover normal power supply.

Until present, there are many methods, such as Artificial Neural Network (ANN)[2], Expert System (ES), Fuzzy Set Theory (FST)[3], Stochastic Optimization Techniques (SOT)[4], Genetic Algorithms (GAs)[5] and Logic Reasoning (LR)[6], etc., which have been applied to fault diagnosis of power system. Petri Nets (PNs), which have the characteristics of parallel information processing and concurrent operating role, is a very convenient and useful modeling tool. 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. In this paper, a method based on PNs models is proposed on the basis of previous work [7, 8]. The Petri Net (PN) model in [7, 8] regards as both high speed and back-up protections. Nevertheless it has to notice the fault diagnosis and relays' behavior evaluation with the help of a template or conclude rules summarized based on the rule of thumb, which might not make the operators understand the results clearly and slow down the diagnosis speed as well.

In addition, when there are false operations of relays or circuit breakers, the diagnosis results might be false. The proposed PN models can spot the fault components fast and exactly, and constitutes reliable and impressive diagnosis results automatically. It can be applied in the power system for not only simple fault, but also multiple faults or the violent faults are made up of the protective devices false operation. This system is good for the fault diagnosis of power system.

Petri net theory

So as to understand the importance of fault diagnosis models easily, the definition and structure of PN are introduced in this section shortly. PN theory was originally developed by the German mathematician Carl Adam Petri in 1960-1962 [7] and 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.

Structure of the petri net

PNs are basically developed for describing and analyzing information flow and they are excellent tools for modeling asynchronous concurrent systems such as computer systems and manufacturing systems, as well as power protection systems. The main structure of a PN is made up of five elements, namely S = (P, T, N, a, β), where P and T are finite nonempty sets of places and transition respectively; N is the token set in the place, and a and β are the directed arcs between P and T [8].

A simple PN model is shown in Fig. 1. Where p_1, p_2, p_3, p_4 are place nodes and t_1, t_2 are transition nodes. The black point in place p_2 is the token. The structure of PN is 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.

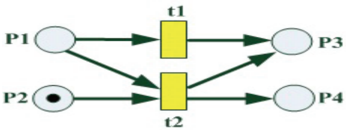

Fig.1. A petri net graph

Matrix description of the petri net

Along with graphical methods, the structure of PNs and the procedure of firing its transitions can be also described and evaluated by matrix operations. The fundamental matrixes are made up of incidence matrix C, the marking vector M and the transition firing vector U. The incidence matrix is used to reveal the topology of a PN. The dimension of this vector is equal to |P|X|T| and is defined as [8]

$$C(p,t)=\begin{pmatrix} -w(p,t), & if\,(p,t)\in F \\ +w(t,p), & if\,(t,p)\in F \\ 0, & otherwises \end{pmatrix}, \qquad (1)$$

where |P| and |T| are the number of elements of P and T sets respectively. w (p,t) is the weight of arc from the place P to the transitions T, and F is the set of arcs. $(p,t)\in F$ means that there is a relation between p and t. As a consequence, the incidence matrix of the PN as shown in Fig. 1 is given by

$$C=\begin{matrix} & t1 & t2 \\ p_1 & -1 & -1 \\ p_2 & 0 & -1 \\ p_3 & 1 & 1 \\ p_4 & 0 & 1 \end{matrix}. \qquad (2)$$

The marking vector M (|P|X 1) is used to exhibit the token marking state of the places. "1" in this vector indicates the number of tokens in the suitable place and "0" means that there are no tokens in the place. The initial state of marking is expressed by M_0. For the Fig. 1, the initial state of marking vector $M_0=\begin{bmatrix}0 & 1 & 0 & 0\end{bmatrix}^T$. Transitions firing vector U (|T|X 1) exhibits that which transition or transitions among t_1, t_2, ...t_m have been fired. The transitions firing vectors of the PN for Fig. 1 are $U_1=\begin{bmatrix}0 & 1\end{bmatrix}^T$ and $U_2=\begin{bmatrix}1 & 0\end{bmatrix}^T$. The dynamic behavior of the PN can be depicted by the following equation [8]

$$M_1 = M_0 + CxU. \qquad (3)$$

Petri net models of the protection scheme

In this section, we firstly present a transmission line model protection relaying scheme, then briefly describe the fault diagnosis model, finally the PN model of the protection scheme is developed. A simple power system is shown in Fig. 2. The PN models of fault diagnosis can be divided into two kinds according to the different coordination logic of the protective devices for a power transmission system. It namely bus model and transmission line model. The generator and transformer can be considered the line or bus elements.

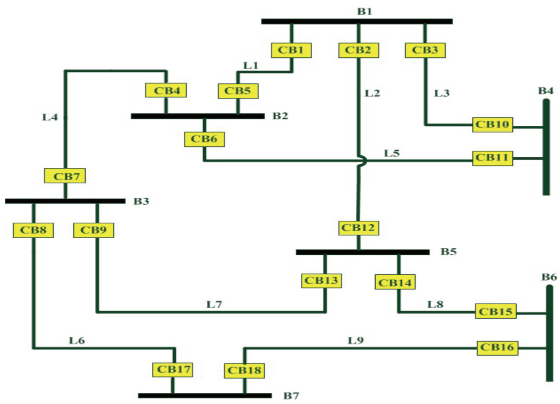

Fig. 2. A simple power system

Bus model

In Fig. 2 we take bus B_3 as A simple. The PN model of the bus is given in Fig. 3. In this model, the transitions T_1, T_2, T_3 and its input places CB_7, CB_8, CB_9 simulate the main protective devices of the bus (B_3). Their operating process, while the transitions T_{1a}, T_{2a}, T_{3a} and its input place CB_4, CB_{13}, CB_{17} simulate the corresponding back-up protective devices. The place B_3 is used to show the state of the bus. The states K_1, K_2, K_3 are virtual nodes, which have no physical meanings.

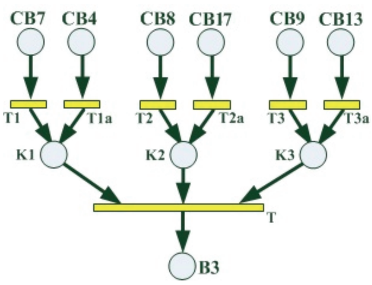

Fig. 3. The fault diagnosis bus model based on PNs

Transmission line model

In Fig. 2 we take the transmission line L_5 as A simple. The PN model of the transmission line is given in Fig. 4.

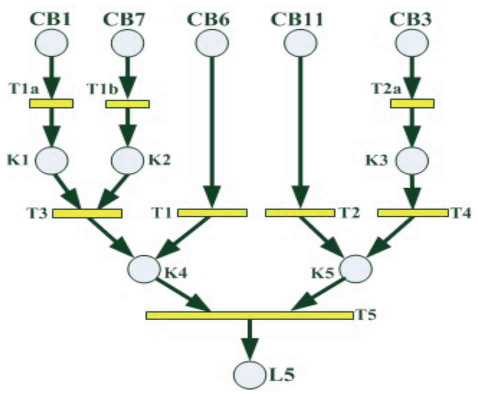

Fig. 4. The fault diagnosis transmission model based on PNs

In this model, the transitions T_1, T_2 and the place CB_6, CB_{11} simulate the main protective devices of the line (L_5). Their operating process, and CB_1, CB_7, T_{1a}, T_{1b} as well as CB_3, T_{2a} simulate the back-up protective devices respectively. The transmission line is simulated by the place L_5. The places K_1, K_2, K_3 as well as K_4, K_5 are virtual nodes, which have no physical meanings.

Fault diagnosis in the transmission line model

The initial tokens are distributed to the places according to the received alarm signals. When the circuit breaker CB_n operates, the place of the breaker CB_n is filled with a token and when the initial token marking process has been finished, the transition node gratifying the firing condition will be fired. The firing condition of the transition T_1 and T_2 is described as follows. The main protection device of the transmission line L_5 operates, and a token presents in the input place of the transition. When the back-up protection device of the transmission line L_5 operates, the transition T_{1a}, T_{1b} and T_{2a} will be fired. A token presents in the input place of the transition.

If all the input places of the transition have tokens inside, the transition T_3, T_4 and T_5 will be fired. After the transitions' firing the tokens will be redistributed in the PN and when there is no transition can be fired the net will achieve its steady state. As a consequence, the faulted components can be identified by the steady PN. If the place L_5 of the steady PN has a token inside, so this transmission line has a fault, otherwise the transmission line is healthy.

A simple power system given in Fig. 2 is still used to illustrate the working process of the suggested PN models. A fault is assumed to happen at line L_5, and protective devices numbered 6, 11 have operated. Think that circuit breaker CB_{11} failed to operate and the fault is cleared by the back-up protective relay at CB_3 and breaker CB_3. Then, incidence matrix C_{L5} can be attained by the structure of the PN model L_5 (shown in Fig. 4) according to the formula (1)

$$C_{L5}=\begin{array}{c} \\ L5 \\ CB_6 \\ CB_1 \\ CB_7 \\ CB_{11} \\ CB_3 \\ K_1 \\ K_2 \\ K_3 \\ K_4 \\ K_5 \end{array}\left(\begin{array}{cccccccc} T_1 & T_{1a} & T_{1b} & T_2 & T_{2a} & T_3 & T_4 & T_5 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & -1 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 & 0 & -1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & -1 \end{array}\right)_{11X8}, \quad (3)$$

Following the above-mentioned rules, the place CB_6 and CB_3 are assigned a token respectively. The initial state of PN model of the transmission line L_5 is given in Fig. 5.

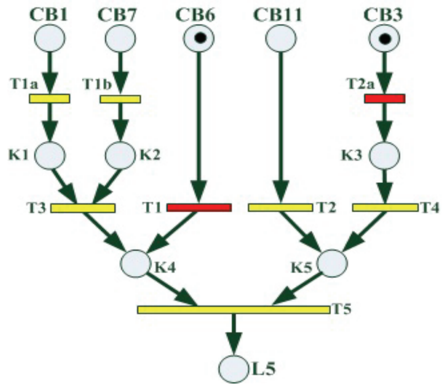

Fig. 5. The initial state of PN model

As a result, the initial marking vector M_0 is given by; $M_0=[0\ 1\ 0\ 0\ 0\ 1\ 0\ 0\ 0\ 0\ 0]^T$. As the transition nodes T_1 and T_{2a} have met the fire condition, these transitions are fired, which make the tokens transfer from the transitions' input place to output place. This is the first fire and it can be described by the state equation (3). $M_{01} = M_0 + C_{L5} \times U_1$. The firing vector U_1 is given by; $U_1=[1\ 0\ 0\ 0\ 1\ 0\ 0\ 0]^T$. The marking vector M_{01} is given by; $M_{01}=[0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 1\ 1\ 0]^T$. The PN model which has finished the first fire is given in Fig. 6.

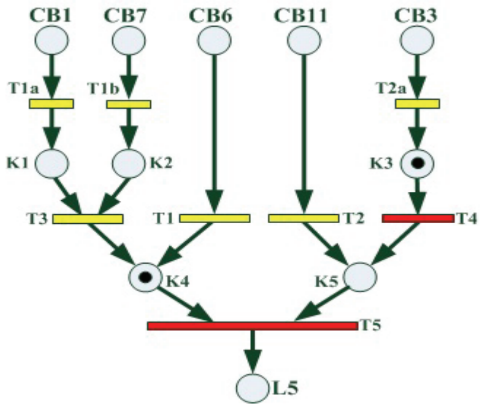

Fig. 6. The first fire state of PN model

After the first fire finished, T4 is the exclusively one in all transitions which can be fired. The firing vector U_2 is given by; $U_2=[0\ 0\ 0\ 0\ 0\ 0\ 1\ 0]^T$. The marking vector M_{02} is given by; $M_{02}=[0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 1\ 1]^T$. $M_{02}=M_{01} + C_{L5} \times U_2$. The PN model which has finished the second fire is given in Fig. 7.

In the next step, the transition T_5 is fired. When this third fire is finished, the PN has no transitions can be fired. The net achieves steady state. The final firing vector U_3 is given by; $U_3=[0\ 0\ 0\ 0\ 0\ 0\ 0\ 1]^T$. The final marking vector M_1 is given by; $M_1=[1\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0]^T$. The steady PN is given in Fig. 8.

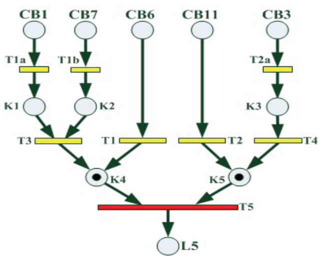

Fig. 7. The second fire state of PN model

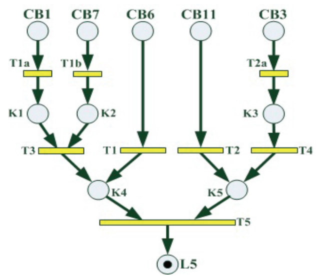

Fig. 8. The steady PN model of transmission line L_5

The place node L_5 in the steady PN has a token inside. For other transmission lines in the simple power system, their steady PNs can also be attained by the similar modeling. The diagnostic process, from which we can know their place nodes corresponding to the lines have no tokens. So, the fault diagnosis results can be attained directly, that is, the line L_5 is fault and other lines have no faults. We no more go into other transmission lines details here.

Conclusions

In this paper a detailed PN model and a simplified PN model of protection scheme for a simple power system are presented. The marked PN model of the system is described in detail. A new approach based on PNs was suggested for modeling of the power system protection systems. This approach provides the possibility of hierarchically monitoring of power system. In this method, the model of protection systems performance has been formulated using PNs and by deductions of protection system data. The proposed system can be easily adapted to the changes in the electric power system. The proposed method uses information from relays and circuit breakers to evaluate the system condition and to make a diagnosis. Nevertheless in the case of broken breaker operating mechanism, or breaker contact failing to interrupt the fault current, it is possible that the breaker auxiliary switches may open and show the Scada that the breaker is open, but in fact the breaker fails to interrupt the fault, and back-up protection still operates. For this case, it is hard to be identified by the proposed PN models. The deduction procedure can be presented graphically in the form of PNs and implemented by matrix operations. This model is good for the fault diagnosis of power system. It shows that the fault diagnosis system based on the proposed models is practicable and effective.

References

1. **Narendra K. G., Sood V. K., Khorasani K., Patel R.** Application of a Radial Basis Function (RBF) Neural Network for Fault Diagnosis in a HVDC System // IEEE Trans. Power Systems, 1998. – No. 13(1). – P. 177–183.
2. **Sun Y., Jiang H., Wang D.** Fault Synthetic Recognition for an EHV Transmission Line Using a Group of Neural Networks with a Time–Space Property // IEE Proc., Generation Transmission Distribution, 1998. – No. 145(3). – P. 265–270.
3. **Lee H. J., Park D. Y., Ahn B. S., Park Y. M., Park J. K., Venkata S. S.** A Fuzzy Expert System for the Integrated Fault Diagnosis // IEEE Trans. Power Delivery, 2000. – No. 15(2). – P. 833–838.
4. **Haas P. J.** Stochastic Petri Nets. – Springer, 2002. – 278 p.
5. **Yang C. F., Bi T. S., Huang S. F., Yang Q. X.** Fault Diagnosis in Power Systems Using Petri Net Approach // Power System Conference of Chinese Universities, 2004. – P. 1412–1415.
6. **Wen F. S., Chang C. S., Tian L.** A Modified Abductive Inference Model for Fault Section Estimation in Power Systems Using The Tabu Search Approach // Electric Machines and Power Systems, 2000. – No. 28(1). – P. 399–414.
7. **Jiang C. J.** Petri Net Theory and its Application. – Higher Education Press, 2003. – 148 p.
8. **Murata T.** Petri Nets: Properties, Analysis and Applications // Proceedings of the IEEE, 1989. – No. 77(4). – P. 541–580.

Received 2011 09 18
Accepted after revision 2011 12 01

N. Pamuk, Y. Uyaroglu. Modeling of Fault Diagnosis in Power Systems using Petri Nets // Electronics and Electrical Engineering. – Kaunas: Technologija, 2012. – No. 2(118). – P. 63–66.

In this paper, an approach of power system fault diagnosis model based on Petri Net (PN) is proposed. The construction of diagnosis model and the method of identifying the faulted components are described in detail. The detailed PN models and relevant conclude process are presented. The proposed system can spot the fault components fast and exactly, and constitutes reliable and impressive diagnosis results automatically. It can be applied in the power system for not only simple fault, but also multiple faults or the violent faults are made up of the protective devices false operation. This system is good for the fault diagnosis of power system. It shows that the fault diagnosis system based on the proposed models is practicable and impressive. Ill. 8, bibl. 8 (in English; abstracts in English and Lithuanian).

N. Pamuk, Y. Uyaroglu. Energijos sistemų gedimų diagnostikos modeliavimas naudojant Petri tinklus // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 2(118). – P. 63–66.

Pasiūlytas energijos sistemų gedimų diagnostikos modelis pagrįstas, Petri tinklais. Detaliai apibūdintas diagnostikos modelio konstravimo procesas ir sugedusių komponentų identifikavimo metodas. Pasiūlytoji sistema greitai ir tiksliai aptinka sugedusius komponentus ir automatiškai pateikia patikimus diagnozės rezultatus. Ji gali būti įdiegta energijos sistemoje ne tik vienetinių, bet ir daugybinių gedimų diagnostikai. Parodyta, kad klaidų diagnostikos sistema, pagrįsta siūlomais metodais, yra praktiškai įgyvendinama. Il. 8, bibl. 8 (anglų kalba; santraukos anglų ir lietuvių k.).