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A PETRI NETS BASED TECHNIQUE FOR FAULT DIAGNOSIS STUDIES IN POWER SYSTEMS

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ABSTRACT

A central controller requires quickly locating and identifying the failure in power systems. The failure analysis based on information taken from the physically distributed protective devices. The process becomes difficult owing to the complexity of the power system increasing. In this study, Petri nets are used as modeling tools to precisely diagnose faults when some uncertain and incomplete alarm information of protective devices is detected. Firstly, a general literature survey of fault diagnosis in power systems is given. Then, models of fault diagnosis based on MATLAB SIMULINK have been developed. A power system network which has 5 buses, 48 over current relays, 48 circuit breakers, 23 transmission lines and 20 loads is used as test network. Finally, the validity and feasibility of the proposed method is demonstrated by simulation examples. The proposed system is tested with nine fault cases. Results of these tests are given in order. It is shown from nine cases that the faulted power system elements can be diagnosed accurately by using the Petri nets based fault diagnosis models.

Key Words: *Petri nets, fault diagnosis, power system, MATLAB/SIMULINK*

GÜÇ SİSTEMLERİNDE ARIZA TEŞHİSİ İÇİN PETRI NET TABANLI BİR YÖNTEM

ÖZET

Güç sistemlerindeki merkezi kontrolcüler, arızanın hızlı bulunmasını ve tanımlanmasına ihtiyaç gösterirler. Hata analizi için bilgiler fiziksel olarak daima koruyucu cihazlardan alınır. Güç sistemi büyüdükçe bu işlemler giderek zorlaşır. Bu çalışmada, koruyucu cihazlardan gelen alarm işlemlerini teşhiste kullanmak için, Petri netler modelleme aracı olarak kullanılmıştır. Çalışmada önce, güç sistemlerinde arıza analizi için genel literatür çalışmaları verilmiştir. .Daha sonar, MATLAB a dayalı arıza teşhisi modelleri geliştirilmiştir. 5 bara, 48 aşırı akım röleli, 48 devre kesicili, 23 iletim hatlı ve 20 yük barındıran bir güç ssitemi devresi, test devresi olarak kullanılmıştır. Teklif edilen metodun geçerliliği ve incelemesi simülasyon örnekleriyle sunulmuştur.

Önerilen sistem, 9 arıza durumu için test edilmiştir. Test sonuçları sıralı olarak verilmiştir.

Anahtar Kelimeler: *Petri nets, arıza teşhisi, güç sistemi, MATLAB/SIMULINK*

1. INTRODUCTION

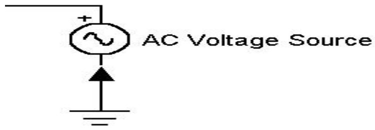
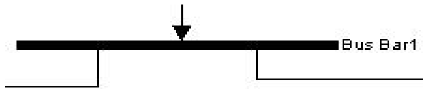
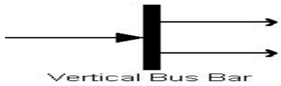
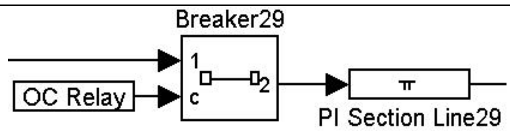
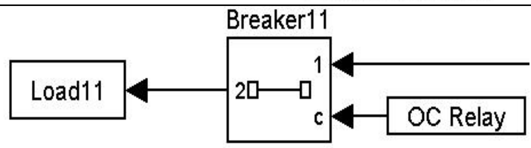
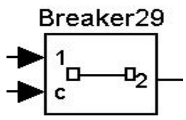
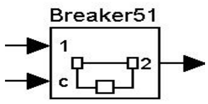
Fault diagnosis in power systems has been conventionally performed by human operators at the control centers based on information collected from distributed sensors. Fault diagnosis requires information from the SCADA system. Basically, when the information comes to the control center, the operators analyze the data and diagnose the fault. The accuracy and speed of the fault diagnosis process depends on the experience of the operators. However, as the complexity of the power systems increase, especially in the case of multiple faults or incorrect operation of the protective devices, the amount of information needing to be processed and evaluated exceed the human capability. For this reason, computer based systems have been developed in helping operators to carry out such complex reasoning process.

In the literature many solutions are proposed for fault diagnosis in power systems. Mainly there are two different approaches to solve the problem: Rule based systems [1-4] and neural network based systems [5,6]. Most of the work in literature use information from circuit breakers and relays which are gathered via SCADA systems. Time information, sequence of events, is also used in some proposed solutions where data is available [7].

Rule based systems share some basic properties: They use knowledge bases which are implemented with IF THEN ELSE statements. This slows down the construction of the fault diagnosis system as a power distribution network needs a lot of rule for its description. They do not take into account the ambiguity in data. Data collected via SCADA may include errors due to communication lines or even the protective equipment may have misoperated. To overcome these problems new methods have been used in the fault diagnosis problem. Rule based systems are mainly domain specific. So changes in network configurations require changes in rules that define the network. Neural network is one of the alternative methods which have been used in pattern recognition problems. Fault diagnosis can be thought as a pattern recognition problem, since when a fault occurs a number of protective devices are expected to operate. One disadvantage of neural networks in fault diagnosis in power distribution network is the long training time. As the changes in distribution network occur frequently, neural network should be trained again with each change. Fuzzy logic [8] is another method used in fault diagnosis. It gives the chance to handle the uncertainties in the system. Fuzzy logic is used with rule based systems to make them more powerful. A fuzzy rule based expert system method is also proposed for power system fault diagnosis [9]. Petri nets have been used for fault diagnosis in recent years. Petri nets are graphical and mathematical modeling tools applicable to many systems. They consist of places, transitions, and arcs that connect them. Input arcs connect places with transitions, while output arcs start at a transition and end at a place. As a graphical tool, Petri nets can be used as a visual communication aid similar to flow charts, block diagrams and networks. Murata [10] have given a detailed properties, analysis and applications of Petri nets in his study. Lo, et al [11], have proposed a power system fault diagnosis using Petri nets. They claimed that with the use of Petri nets processing time has reduced and accuracy has increased when compared with traditional methods. Hadjicostis and Verghese [12] have proposed a Petri net based study that allows concurrent/incremental processing of the information that arrives at the controller and only requires simple calculations during execution time. Liu and Chiou [13] have showed that Petri nets are more efficient than fault trees for failure analysis. Frankowiak, et al [14], have presented a Petri-net based distributed monitoring system with PIC microcontroller.

In this study a Petri nets based solution to the fault diagnosis in electrical distribution systems have been developed. A power system network which has 5 buses, 48 over current relays, 48 circuit breakers, 23 transmission lines and 20 loads is used as test network. This network and all other components of the systems are developed with MATLAB and SIMULINK toolboxes. Models used in the study are given in Table 1. Fig. 1. shows model of the over current relay and Fig. 2. shows test network used in the study. Load flow analysis is made for the test network and outputs of the analysis (status of circuit breakers, relays and current flowing through circuit breakers) are used for fault diagnosis. With the proposed system one can take information about the protective devices. System is able to differentiate the misoperation, failing to operate and correct operations of the relays and breakers. System does not use any data base files for rules or patterns. So system works fast enough for online applications. Developed system uses MATLAB for generation of relay, circuit breaker status information and load flow analysis which gives current passing through circuit breaker. In a real world application these information will be expected from real distribution network via SCADA system.

Table 1. MATLAB model of power system components

Component of power system	MATLAB model of component
AC Voltage source	
Horizontal bus bar model	
Vertical bus bar model	
PI section line model	
Load protected with breaker and over current relay	
Breaker model without snubber circuit	
Breaker model with snubber circuit	

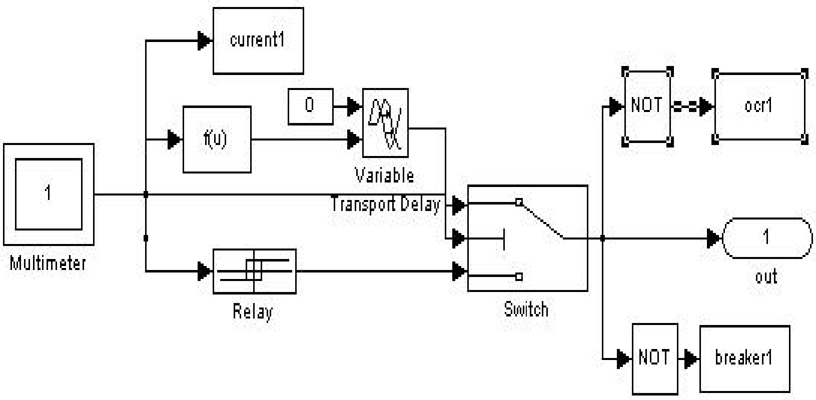


Fig. 1. Model of the over current relay

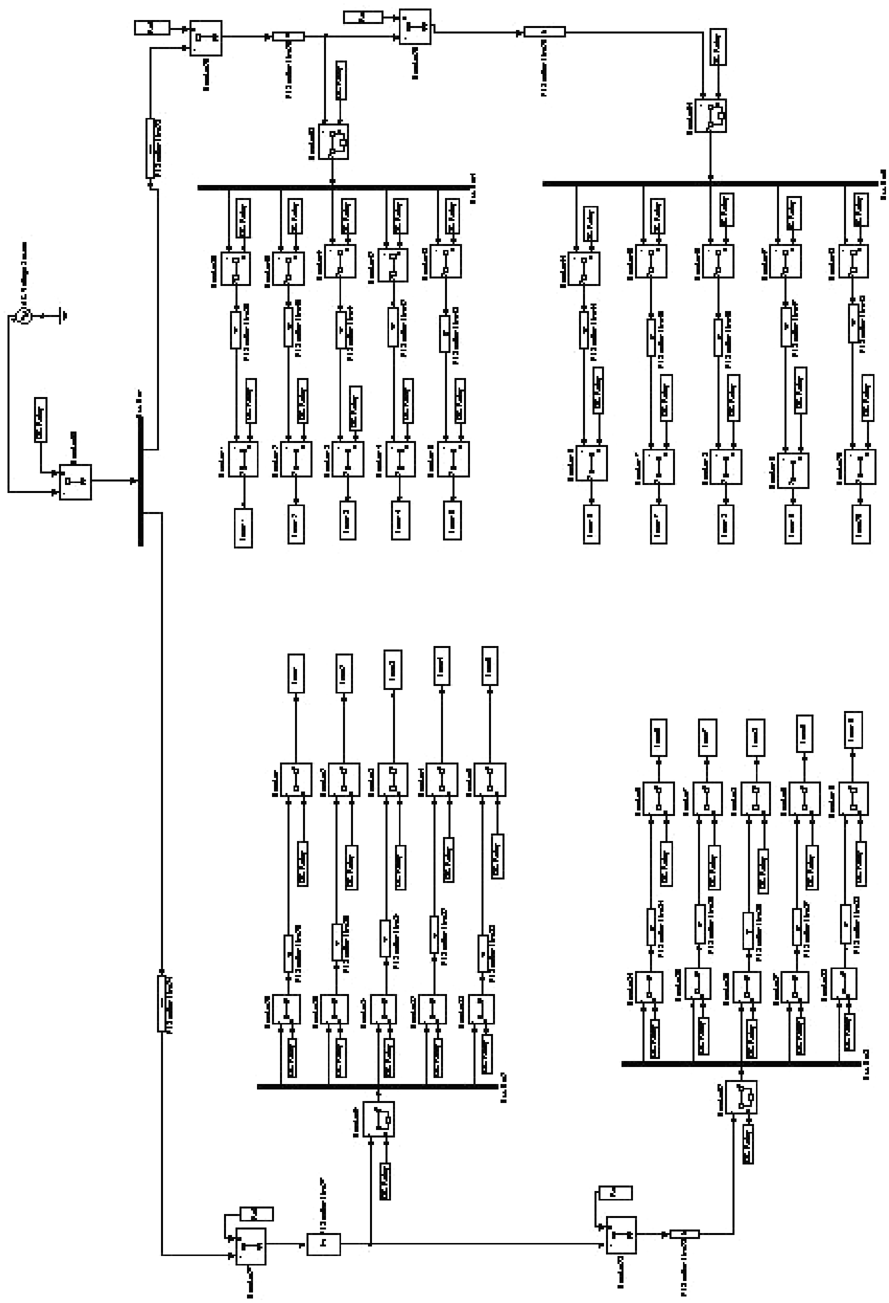


Fig. 2. Test network used in the study

2. PETRI NETS

In this study a system using Petri nets of fault diagnosis in power systems has been proposed. This system is chosen as becomes possible to reduce diagnosis time and increase correctness of results when compared with traditional pattern recognition or neural network based systems. Proposed system can easily be adapted to different power system network configurations. It is also suitable to online applications. Petri nets were developed by Carl Adam Petri and are mainly used to model asynchronous and concurrent systems. A Petri net is a collection of directed arcs connecting states (or places) and transitions. States may hold tokens. Petri nets are used in computer systems, manufacturing systems and power protection systems modeling [10]. A Petri net N is defined by the set of states S, the set of transitions T, the input function Pre, and the output function Post. With the help of the Petri net in Fig. 3, it is easier to make these more clear:

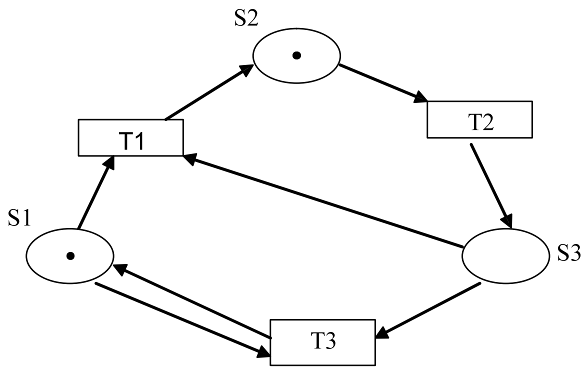


Fig. 3. A Petri net model

First, three special matrices should be formed which are used to explain relations in the net: Pre, Post and C matrices. All three matrices have S rows and T columns. First the Pre matrix will be explained. If there is an arc from a state to a transition then corresponding element of the Pre matrix has a value which is equal to capacity of the arc, else value of that element is 0. Hence the Pre matrix is formed as:

$$\Pr e = \begin{matrix} & t1 & t2 & t3 \\ s1 & 1 & 0 & 0 \\ s2 & 0 & 1 & 0 \\ s3 & 1 & 0 & 1 \end{matrix} \qquad (1)$$

If there is an arc from a transition to a state then corresponding element of the Post matrix has a value which is equal to capacity of the arc, else the value of that element is 0. Hence the Post matrix is formed as:

$$Post = \begin{matrix} & t1 & t2 & t3 \\ s1 & 0 & 0 & 1 \\ s2 & 1 & 0 & 0 \\ s3 & 0 & 1 & 1 \end{matrix} \qquad (2)$$

Topological structure of a Petri net is represented with C matrix. C matrix is defined as :

$$C(s,t) = \begin{Bmatrix} -W(s,t) & if\ f(s,t) \in F \\ +W(s,t) & if\ f(t,s) \in F \\ 0 & otherwise \end{Bmatrix} \qquad (3)$$

where $W(s,t)$ is the weight of the arc from state (s) to transition (t) and F is the flow relation between state and transition. Hence:

$$C = \begin{array}{c|ccc} & t1 & t2 & t3 \\ s1 & -1 & 0 & 1 \\ s2 & 1 & -1 & 0 \\ s3 & -1 & 1 & 0 \end{array} \qquad (4)$$

Token distribution is shown with marking vector. So for the Petri net the initial marking vector $M_0(s)$ is: $\begin{bmatrix}1 & 1 & 0\end{bmatrix}^T$. Maximum number of token that a place can hold is shown by K(s).
Structure of the net is static. Markings and executions define the dynamic properties of the net. Execution is defined as the firing of the transition of a net which changes the marking of the net by moving tokens from their input places to their output places. A transition is enabled if all its input places have at least the same number of tokens as the multiplicity of the input arc and unless the capacity of the output places exceeds after the transition firing.

$$M_1(s) = \begin{Bmatrix} M_0(s) - W(s,t) & if\ f(s,t) \in F \\ M_0(s) + W(s,t) & if\ f(t,s) \in F \\ M_0(s) & otherwise \end{Bmatrix} \qquad (5)$$

From Eq. 3 and Eq. 5, if there is an initial marking $M_0(s)$, which enables the *k*th transition, it can be seen that $M_1(s)$ is simply the addition of the *k*th column of matrix C and the marking $M_0(s)$.

$$M_1(s) = M_0(s) + CU \qquad (6)$$

In Eq. 6 *U* is a vector whose elements are the number of occurrences of t_n in a series of transition firing.

3.1. Proposed System With Petri Nets
Petri net is used in the following way. Elements which are suspected to be faulty, transmission line or bus bar, relays and circuit breakers form States (S). Transmissions are formed with fault transition and time stamps. In Fig. 4, a part of the network is shown. Node N is protected by CB and a relay.

In Fig. 4, Node N shows the protected equipment. CB1 and R1 are circuit breaker and relay protecting N1 respectively. Dm is a dummy place. Initially there is a token in both R1 and N1. When a fault occurs at N1 with transition Tr2 token comes to Dm. Transition Tr1, where Tr1 represents the time stamps, creates a token at CB1. A token at CB1 shows that CB1 has operated to clear the fault at N1. When a fault occurs at Node N available information will be relay and circuit breaker status. Token will be at state CB, if CB had operated and with transition Tr2 it will propagate to states Dummy and Relay. When there is a token at state Dummy it will propagate to state Node N with transition Tr1. So for fault diagnosis, model in Fig. 4 should be reversed. In Fig. 5, the reversed model of the one in Fig. 4 is shown.

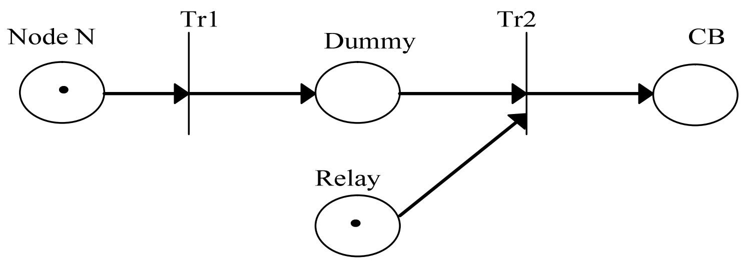


Fig. 4. Petri net model of a part of network

Initial marking for the model in Fig. 5 is formed with the signals coming from system, status of circuit breakers. If circuit breaker has opened than its input is set to “1”, otherwise it is set to “0”. For Node N, Relay and Dummy states initial markings are set to “0”. If circuit breaker has operated than the corresponding initial marking vector $M_0(s)$ will be:

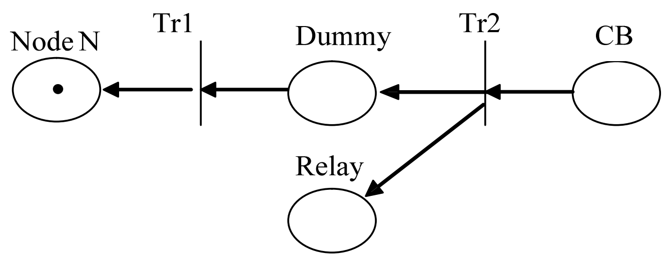


Fig. 5. Backward Petri net model of network in Fig. 4.

$$M_0(s) = \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \end{bmatrix} \begin{matrix} Node\,N \\ Dummy \\ CB \\ \mathrm{Re}lay \end{matrix} \qquad (7)$$

Next marking of the Petri net is calculated using Eqn. 3. For that C matrix should be formed, which is equal to Post – Pre. Hence first Pre and Post matrices should be formed.

$$\mathrm{Pr}\,e = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & 0 \end{bmatrix} \begin{matrix} Node\,N \\ Dummy \\ CB \\ \mathrm{Re}lay \end{matrix} \qquad (8)$$

$$Post = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 1 \end{bmatrix} \begin{matrix} Node\,N \\ Dummy \\ CB \\ \mathrm{Re}lay \end{matrix} \qquad (9)$$

where first column is for Tr1 and second for Tr2. Now C = Post – Pre:

$$C = \begin{bmatrix} 1 & 0 \\ -1 & 1 \\ 0 & -1 \\ 0 & 1 \end{bmatrix} \begin{matrix} Node\,N \\ Dummy \\ CB \\ \mathrm{Re}lay \end{matrix} \qquad (10)$$

U vector is formed by time stamps of the relay operations. If time stamp exist than value of Tr2 is set to “1”, otherwise to “0”. Value for Tr1 is always set to “1”. From Eq. 3 $M_1(s)$ is calculated as:

$$M_1(s) = \begin{bmatrix} 1 \\ 0 \\ 1 \\ 0 \end{bmatrix} \begin{matrix} Node\,N \\ Dummy \\ CB \\ \mathrm{Re}lay \end{matrix} \qquad (11)$$

As Node N has a value “1” in the final marking vector it is stated that there is a fault at Node N. Possible ambiguities in the operation of the relays and circuit breakers are also handled with the proposed system. Value of circuit breaker in initial marking vector is compared with the one in the final marking vector. A truth table, Table 2, is used to make a decision on the operation of circuit breaker. Same idea is used for relays; the only difference is that the truth table for relays, Table 3, is different.

Table 2. Truth table for circuit breaker

Value in $M_0(s)$	**Value in $M_1(s)$**	**Comment**
1	0	Operated Correctly
0	0	No Operation is Required
0	-1	Failed to Operate
1	1	Misopeated

Table 3. Truth table for over current relay

Value in $M_0(s)$	**Value in $M_1(s)$**	**Comment**
1	1	Operated Correctly
0	0	No Operation is Required
0	1	Failed to Operate
1	0	Misopeated

3.2. Realization Of Proposed System With MATLAB SIMULINK

The test network developed is used for informative signal generation. Simulation made in MATLAB is actually simulation of a SCADA system. It gives status information of relays, circuit breakers and the current passing through circuit breakers. For this, model files (*.mdl) and M files (*.m) are developed. M files are used for decision making with respect to the incoming signals. The model file developed with SIMULINK is shown in Fig. 6.

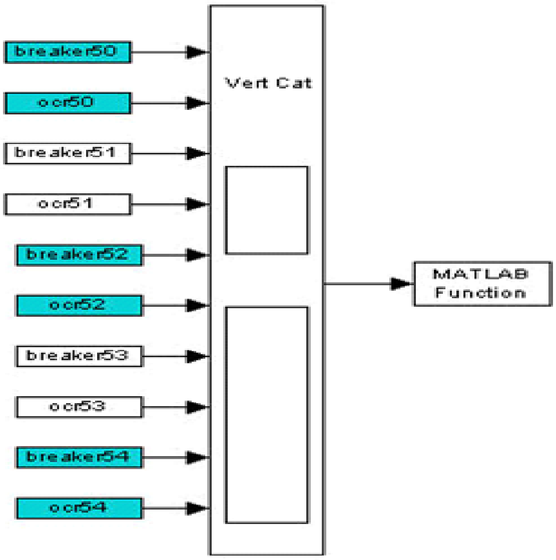


Fig. 6. A part of petripaper.mdl file

In the petripaper.mdl status information of breakers and over current relays are passed to the M files which will use to make the decision. Vector concatenator elements are used for this purpose. C matrix is same for all elements of the test network as all of them are protected with single circuit breaker and over current relay combination. So C matrix is not taken as a variable. It is directly put to the M file. There are 3 different M files for the decision. Actually one M file would be enough but then in order to pass all variables to that M file a vector concatenator of 96 inputs would be needed and it would become hard to examine the model file.

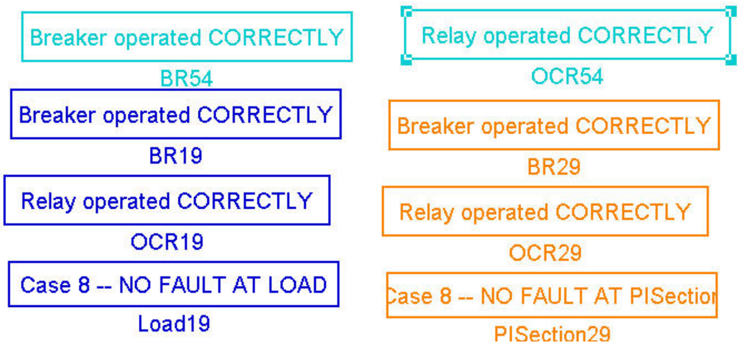


Fig. 7. A part of petriresults.mdl file

To display the results of the analysis another petriresults.mdl model file was developed as seen in Fig. 7. There are 3 information boxes for each bus bar, pi section line and load. One for breaker information, one for relay information and one for the node information. Hence there are totally 147 information boxes. Name of each element is shown at the bottom of each box. These boxes have different foreground color for easiness in examining. When there is a fault in an element then background color of corresponding information box is set to red.

M files are used for decision making. In this M file and in func_petribus.m, func_petripisection.m files C matrix is ready. From the vector concatenator relay and circuit breaker information are taken, with these information

$M_0(s)$ vector and U matrix are formed. C matrix and U matrix are multiplied and $M_0(s)$ is added to the multiplication. With this addition $M_1(s)$ is reached.
Corresponding values of circuit breakers, relays and nodes are taken from this $M_1(s)$.

- When value for a node in $M_1(s)$ is equal to "1", there is a token at state node, then it is concluded that there may be fault at that node.
- When value for a relay in $M_1(s)$ is equal to "1", there is a token at state relay, then it is concluded that relay is supposed to operate.
- If there is token at node and all relays which are used to protect that node are supposed to operate then node is assumed to be faulty.

Operations of relays and circuit breakers may not be correct. Relay may not sense the over current and could not send the trip signal to the circuit breaker. Circuit breaker may have failed to operate although it has received trip signal. Truth tables namely Table 2 and Table 3 are used to eliminate these uncertainties. For this purpose values of relays and circuit breakers in $M_0(s)$ and the ones in $M_1(s)$ are compared. Comparisons are made with IF THEN ELSE structures using truth tables. Decisions given are send to corresponding information boxes in petriresults.mdl file. It can be seen that decisions depend on the status information of circuit breakers and over current relays. Current information is not used in the system. This causes some problems such as false operation of over current relay may not be detected.

4. SIMULATION RESULTS

Proposed systems are tested with the power distribution system model which is described in the study. In normal conditions maximum voltage of the voltage source is set to 34.5 kV, threshold value of the over current relays protecting loads are set to 30 A, which are approximately ten times than the normal operating current passing through them. System is tested with following fault conditions while simulation is continuing under normal conditions:

1. A fault is developed at load 4 by manipulating the load such that current passing through it becomes higher than the threshold value of the over current relay 4. Over current relay 4 has sent trip signal to the circuit breaker 4 and circuit breaker 4 has opened the circuit.
2. A fault is developed at load 4 as described in case 1. This time over current relay 4 has failed to operate. No trip signal has sent to circuit breaker 4. Circuit breaker 4 has operated correctly and has not opened the circuit.
3. With the fault at load 4, over current relay 4 has failed to operate and has not sent trip signal to the circuit breaker 4. Circuit breaker 4 has misoperated and opened the circuit.
4. With the fault at load 4, over current relay 4 has operated correctly and has sent trip signal to the circuit breaker 4, but circuit breaker 4 has failed to operate.
5. There is no fault at load 4, over current relay 4 has operated correctly and has not sent trip signal to the circuit breaker 4, but circuit breaker 4 has misoperated and opened the circuit.
6. There is no fault at load 4, over current relay has misoperated and has sent trip signal to the circuit breaker 4. Circuit breaker 4 has operated correctly and has opened the circuit.
7. There is no fault at load 4, over current relay has misoperated and has sent trip signal to the circuit breaker 4. Circuit breaker 4 has misoperated also and has not opened the circuit.
8. In this fault case there are two faults in the network. One of which is at load 4 and second is at load 15. Both of the protective devices of the loads have operated correctly.
9. There is fault at load 4. Circuit breaker 4 and over current relay 4 has operated correctly but the circuit breaker 32 has misoperated and opened the circuit.

   Nine different fault situations are described above. Except two of the fault cases in which both circuit breaker and relay has operated correctly, seven of the fault cases have faulty operation of either circuit breaker or over current relay or both.

   The proposed system is tested with nine fault cases. Results of the tests are given below:

Fault case 1

From the status information of circuit breaker and over current relay, values for circuit breaker 4 and over current relay 4 in the M_0 marking vector are 1 and 1 respectively. After operations values for breaker 4 and relay 4 in the final marking vector are 0 and 1 respectively. Value for the load 4 in the final marking vector is 1. So it is concluded that there is fault at load 4 and both relay and breaker has operated correctly. In Fig. 8, information boxes for Load 4 in the petriresults.mdl file are shown.

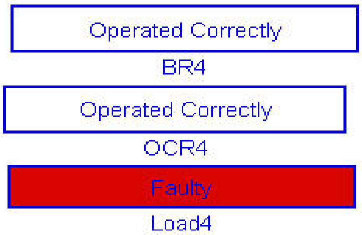


Fig. 8. System with Petri nets for fault case 1

Fault case 2

From the status information of circuit breaker and over current relay, values for circuit breaker 4 and over current relay 4 in the M_0 marking vector are 1 and 0 respectively. After operations values for circuit breaker 4 and over current relay 4 in the final marking vector are 1 and 0 respectively. Value for the load 4 in the final marking vector is 0. In this fault case value for the transmission line 32 is 1 in the final marking vector. Values of circuit breaker 32 and over current relay 32 in the initial marking vector are 1 and 1 respectively. After operations values for circuit breaker 32 and over current relay 32 in the final marking vector are 0 and 1 respectively. So it is concluded that there is no fault at load 4. Over current relay 4 did not require any operation and circuit breaker 4 has misoperated. But there is fault at transmission line 32 and both of the protective devices of transmission line 32 have operated correctly. In Fig. 9, information boxes for Load 4 and for transmission line 32 in the petriresults.mdl file are shown.

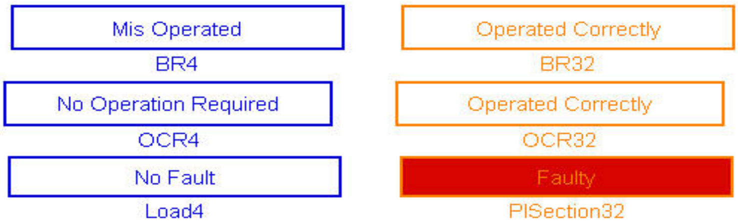


Fig. 9. System with Petri nets for fault case 2

Fault case 3

From the status information of circuit breaker and over current relay, values for circuit breaker 4 and over current relay 4 in the M_0 marking vector is 0 and 0 respectively. After operations values for breaker 4 and relay 4 in the final marking vector are 0 and 0 respectively. Value for the load 4 in the final marking vector is 0. So it is concluded that there is no fault at load 4. Over current relay 4 did not require any operation and circuit breaker 4 has misoperated. In Fig. 10, information boxes for Load 4 in the petriresults.mdl file are shown.

Fig. 10. System with Petri nets for fault case 3

Fault case 4

From the status information of circuit breaker and over current relay, values for circuit breaker 4 and over current relay 4 in the M_0 marking vector is 0 and 0 respectively. After operations values for breaker 4 and relay 4 in the final marking vector is 0 and 0 respectively. Value for the load 4 in the final marking vector is 0. In this fault case value for the transmission line 32 is 1 in the final marking vector. Values of circuit breaker 32 and over current relay 32 in the initial marking vector are 1 and 1 respectively. After operations values for circuit breaker 32 and over current relay 32 in the final marking vector are 0 and 1 respectively. So it is concluded that there is no fault at load 4. Over current relay 4 did not require any operation and circuit breaker 4 has misoperated. But there is fault at transmission line 32 and both of the protective devices of transmission line 32 have operated correctly. In Fig. 11, information boxes for Load 4 and for transmission line 32 in the petriresults.mdl file are shown.

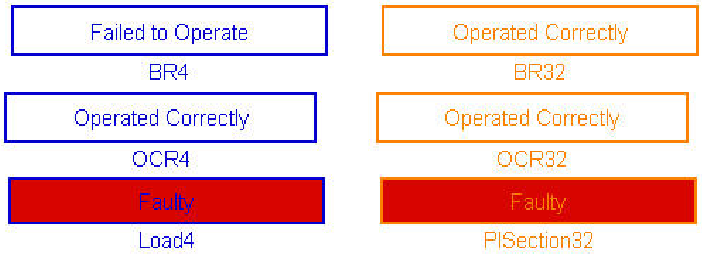


Fig. 11. System with Petri nets for fault case 4

Fault case 5

From the status information of circuit breaker and over current relay, values for circuit breaker 4 and over current relay 4 in the M_0 marking vector are 1 and 0 respectively. After operations values for breaker 4 and relay 4 in the final marking vector are 1 and 0 respectively. Value for the load 4 in the final marking vector is 0. So it is concluded that there is no fault at load 4. Over current relay 4 did not require any operation and circuit breaker 4 has misoperated. In Fig. 12, information boxes for Load 4 in the petriresults.mdl file are shown.

Fig. 12. System with Petri nets for fault case 5

Fault case 6

From the status information of circuit breaker and over current relay, values for circuit breaker 4 and over current relay 4 in the M_0 marking vector are 1 and 0 respectively. After operations values for breaker 4 and relay 4 in the final marking vector are 1 and 0 respectively. Value for the load 4 in the final marking vector is 0. So it is concluded that there is a fault at load 4. Over current relay 4 operated correctly and circuit breaker 4 has operated correctly. In Fig. 13, information boxes for Load 4 in the petriresults.mdl file are shown.

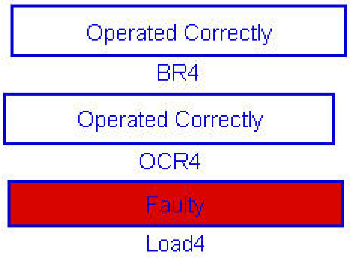


Fig. 13. System with Petri nets for fault case 6

Fault case 7

From the status information of circuit breaker and over current relay, values for circuit breaker 4 and over current relay 4 in the M_0 marking vector are 0 and 1 respectively. After operations values for breaker 4 and relay 4 in the final marking vector are -1 and 1 respectively. Value for the load 4 in the final marking vector is 1. So it is concluded that there is a fault at load 4. Over current relay 4 operated correctly and circuit breaker 4 has failed to operate. In Fig. 14, information boxes for Load 4 in the petriresults.mdl file are shown.

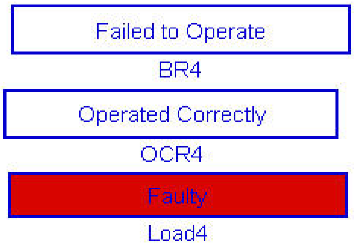


Fig. 14. System with Petri nets for fault case 7

Fault case 8

From the status information of circuit breaker and over current relay, values for circuit breaker 4, over current relay 4, circuit breaker 15 and over current relay 15 in the M_0 marking vector are all 1. After operations values for breaker 4 and relay 4 in the final marking vector are 0 and 1 respectively. Values for breaker 15 and relay 15 in the final marking vector are 0 and 1 respectively. Values for the load 4 and for the load 15 in the final marking vector are both 1. So it is concluded that there are faults at load 4 and at load 15. Protective devices of both loads have operated correctly. In Fig. 15, information boxes for Load 4 and Load 15 in the petriresults.mdl file are shown.

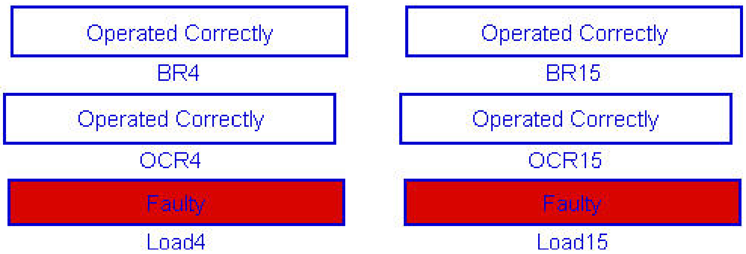


Fig. 15. System with Petri nets for fault case 8

Fault case 9

From the status information of circuit breaker and over current relay, values for circuit breaker 4, over current relay 4, circuit breaker 32 and over current relay 32 in the M_0 marking vector are all 0, except circuit breaker 32. After operations values for breaker 4 and relay 4 in the final marking vector are both 0. Values for breaker 15 and relay 15 in the final marking vector are 1 and 0 respectively. Values for the load 4 and for the load 15 in the final marking vector are both 0. So it is concluded that there is no fault at load 4. Protective devices of load 4 did not require any operation. Circuit breaker 32 has misoperated. In Fig. 16, information boxes for Load 4 in the petriresults.mdl file are shown.

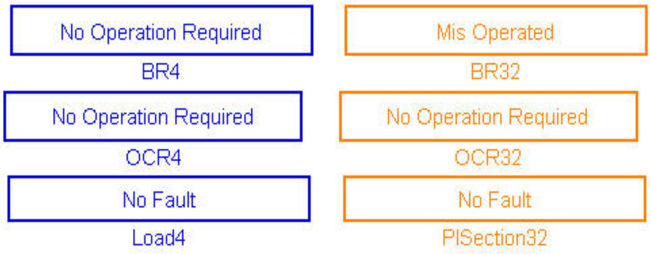


Fig. 16. System with Petri nets for fault case 9

From the seven fault cases which are described above it is obviously seen that system with Petri nets may not give correct decisions when the over current relay has misoperated. This is because of not using the current measurement information.

5. CONCLUSIONS

In this study Petri nets based solution to the electrical power distribution network fault diagnosis problem is proposed. Proposed system is able to diagnose multiple faults and faulty operations of the protective devices. Multiple fault diagnosis is an important feature. This is achieved by modularity in the proposed solutions. With this modularity the proposed system can be easily adopted to the changes in the electrical power distribution networks. As it is known changes occur quite frequently. It is also possible to adopt the proposed system to the real life applications. The only thing that should be made is to replace the source of the information form MATLAB Simulink to SCADA. Proposed system has not got the problem of long training time as the neural network based systems have. Also slow execution time problem is not faced with the proposed system.

Petri nets solution depends on status information of circuit breakers and relays. It is modular and expandable. It also gives information about the correctness of the operations of relays and circuit breakers. It does not use current information. So decisions given about the operations of the protective devices do not depend on measured quantities. This yields wrong decisions when the status information of relay is wrong. System developed with Petri nets does not give correct decision if the over current relay is misoperated. Misoperation of relay is defined as although current passing through the circuit breaker is smaller than the threshold of the over current relay, relay sends trip signal to the breaker. Rule based system uses status information of relays and circuit breakers. Also current passing through the circuit breaker is also taken into account. Comparisons are made with the incoming status information and the current value. Misoperated and failed to operate cases can be distinguished from correct operation cases. The system developed is modular and can easily be applied to different network configurations. Also system is adaptable to the changes in the network configurations.

Proposed rule based system is fast enough for online applications. The main problem in applying this system to real life is that in distribution systems in Turkey, information from network is usually not available. With the recent developments in electrical energy market it is hoped that new technologies will be applied to the distribution networks so as to increase the customer satisfaction.

The rule based system can be developed further to handle corrupted signals of status information of relays and circuit breakers. For this it is planned to use a copy of the tested network. In the copied network, incoming breaker status information will be used to control the input of the circuit breaker. After applying a load flow analysis to the copied network, currents from copied network and original network will be compared. By this it is believed that rule based system will be able to handle corrupted information signals also.

In the proposed system each protected device is modeled separately. Coordination of protective devices, back up protection, is not taken into account. When these are taken into consideration then the system will be network configuration dependent and it should be changed as the network configuration changes.

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