Diagnosis of Fault Type by Dissolved Gas Analysis in Transformer Oil Using Petri Net Technology

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Abstract

Petri net technology can be applied easily in large and complex power systems because of its parallel processing. Fault diagnosis by dissolved gas analysis in transformer oil can be previously identified, so the reliability of the system can be increased and the operator working in substation can be accelerated against the intervention of a fault. In this study, reliability characteristics of the electric power transformer were obtained using petri net technology which was produced more successful results than mathematical and heuristic methods. Applied fault diagnosis method is simple and an effective than other methods. PIPE2 software was used during the computer simulation. The fast fault diagnoses respond had obtained by using this method. Possible fault types in the electric power transformer were predetermined and were aimed to minimize staff intervention.

Keywords: *Power transformer, Petri nets technology, Fault type diagnosis.*

Petri Ağı Teknolojisi Kullanılarak Transformatör Yağındaki Çözünmüş Gaz Analizi ile Arıza Tipinin Tespiti

Özet

Paralel işlem yapabilmesinden dolayı Petri ağı teknolojisi büyük ve karmaşık güç sistemlerinde rahatlıkla uygulanabilmektedir. Transformatör yağında çözünmüş gaz analizi ile arıza teşhisi önceden tanımlanabilmekte, böylece sistemin güvenilirliği artmakta ve transformatör merkezinde çalışan operatörün arızaya karşı müdahalesi hızlanmaktadır. Bu çalışmada, elektrik güç transformatörlerinin güvenilirlik karakteristikleri Petri ağı teknolojisi kullanılarak elde edilmiş, matematiksel ve sezgisel metotlardan daha başarılı sonuçlar ortaya konmuştur. Uygulanan arıza teşhis metodu diğer metotlardan daha basit ve etkilidir. Bilgisayar simülasyonlarında PIPE2 programı kullanılmıştır. Bu metot kullanılarak hızlı arıza teşhis cevapları elde edilmiştir. Elektrik güç transformatörlerindeki muhtemel arıza tipleri önceden tespit edilmiş ve personel müdahalesinin en aza indirgenmesi hedeflenmiştir.

Anahtar kelimeler: *Güç transformatörü, Petri ağları teknolojisi, Arıza tipi tespiti.*

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1. Introduction

Since the recent 10 years, the principal problem of the large power grid is to guarantee it's confident and reliability, in which power transformer is the significant equipment. So as to increase the security performance and economic efficiency, it is obligatory to evaluate the power transformer performance and to diagnose the inner confidential faults, and make the responds and interprets. In the 21th, field experts have performed profound research on the power transformer fault diagnosis, and have made some successes on Artificial Neural Network (ANN) and Expert System (ES) [1].

Inception results are supporting, nevertheless some limitations exist. Given such limitations, a new power transformer fault diagnosis model based on the petri nets has been established by the researchers of the Turkish Electricity Transmission Company (TETC). Application of the convenient samples is used to encourage its amendment. It shows that the application of the petri nets obtains a new fast instrument for power transformer fault diagnosis.

2. Petri Nets Theory

The opinion of the petri net was first introduced by Carl Adam Petri, 1962, in his doctoral dissertation [2]. The petri nets based on network and mathematical theory are performed to defining the discrete events' relationship and attitude in diagrammatic procedure as well as to defining the asynchronous parallel computer system model and to analyzing parallel or concurrent systems, which are agreeing more and more popular in the Artificial Intelligence (AI) field [3]. Furthermore the stiff mathematical representation, the direct viewing diagrammatic is another way to indicate the petri nets.

The petri nets are described by the affluent system characterization procedure and the system behavioral analysis technology. It obtains the tangible opinion basis for computer technique. In this study, I established the petri net model for power transformer fault diagnosis. Compared with ES, the petri nets in use of simple matrix are capable of curtail the time of examination and increase the sensibility. In the petri nets, the definition of the system formation is described as net, which, as a matter of fact, is a bidirectional graphic without isolate nodes. It is described as follows [4].

Definition 1: A triple N = (P,T,F) convincing the following three situations is called as a net.

$$P \cup T \neq \varnothing \tag{1}$$

$$P \cap T = \varnothing \tag{2}$$

$$F(PXT) \cup (\mathrm{TXP}) \tag{3}$$

$$Dom(F) \cup Cod(\mathrm{F}) = \mathrm{P} \cup \mathrm{T} \tag{4}$$

where;

$$Dom(F) = \{\mathrm{x} \in P \cup T \,|\, \exists\, y \in P \cup T : (\mathrm{x}, \mathrm{y}) \in F\} \tag{5}$$

$$Cod(F) = \{\mathrm{x} \in P \cup T \,|\, \exists\, y \in P \cup T : (\mathrm{y}, \mathrm{x}) \in F\} \tag{6}$$

P = {p_1, p_2, ….,p_n} is a finite set of places, T = {t_1, t_2, ….,t_n} is a finite set of transitions, P ∪ T = V, where V is the set of vertices and P ∩ T = Ø. In diagrammatic representation, places are drawn as circles, and transitions as either bars or boxes. A simple of petri nets graph is shown in figure 1.

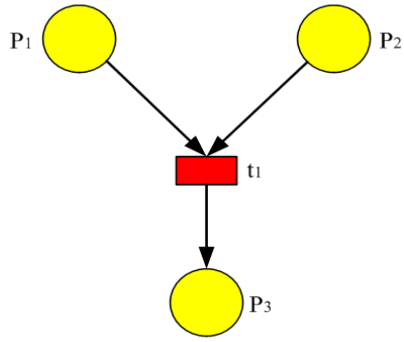

Figure 1. Petri nets graph

Definition 2: Assumed that N = (P,T,F) is a net, and x ∈ P ∪ T.

$$\bullet x = \{y \mid y \in P \cup T \wedge (x, y) \in F\} \quad (7)$$

$$x \bullet = \{y \mid y \in P \cup T \wedge (y, x) \in F\} \quad (8)$$

•x is called input set and x• is called output set. Supplemented into a match M:P→{0,1,2,....} named marking, the above net becomes a tetrad with marking, which is designated as follows [5]:

$$N = (P, T; F, M) \quad (9)$$

If a marking (state) designates to each place "p" a nonnegative integer k, it is called that "p" is marked with k tokens. Limning, k black dots (tokens) are placed in "P". The solely execution rule in a petri nets are the rule for transition providing and firing. A transition "t" is considered as enables if each input places "p" of "t" is marked with at least k (k > 0) tokens. The transition firing situation graphs are shown in figure 2.

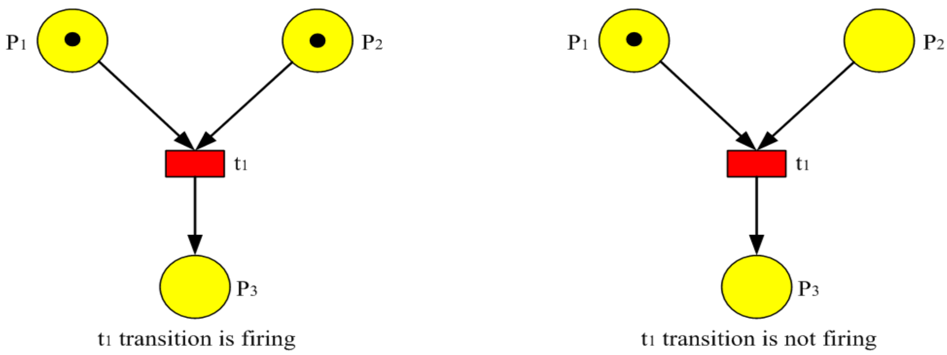

Figure 2. Transition firing graphs

Each initial marking M_0 has a subsequent accessible marking regarding it. A specific model is presented in this paper in which the output place "p" of each transition "t" is peerless and the output place "p" of each transition "t" has no output transition "t".

Pointing at the fast known of the result of the transition firing, the description and reasoning duration are given in the next paragraph.

Definition 3: Presumed that $\sum = (P, T, F, M)$ is a petri nets, where $P = \{p_1, p_2, ... p_m\}$, $T=\{t_1, t_2, ... t_n\}$, then the formation of the petri net could be represented with a matrix $A=[a_{ij}]_{nxm}$;

$$a_{ij} = \begin{cases} 1, & if (t_i, p_j) \in F \\ 0, & or \quad else, \end{cases} \qquad i \in \{1,2,....,n\}, \quad j \in \{1,2,....,m\} \tag{10}$$

$$a_{ij} = \begin{cases} 1, & if (p_j, t_i) \in F \\ 0, & or \quad else, \end{cases} \qquad i \in \{1,2,....,n\}, \quad j \in \{1,2,....,m\} \tag{11}$$

For: A is $\sum$ incidence matrix, $A^+ = [a_{ij}^+]_{nxm}$, $A^- = [a_{ij}^-]_{nxm}$, is $\sum$ output / input matrix [6].

The reasoning duration of the model;
1-) Describing a vector $B = A^{-T}$, $B = [B_1, B_2, ...B_n]$, where B_i is the column vector of matrix B.
2-) Describing a novel vector $E_i = [0\ 0 \ldots 0\ 1\ 0 \ldots 0]'_{1xn}$, the location number of 1 equals to i, i=1,2,….n. M (p) = 0 or M (p) = 1.
3-) If $M_j = B \bullet E_i$, then $M_{j+1} = M_j + (E_i \bullet A)'$, j = 0,1,2,…..m and If $M_{j+1} = M_j$, then over.

This reasoning duration unties conflict problem in the model. It is decisive transition t firing rightly.

3. Fault Diagnosis Model in Transformer Oil Using Dissolved Gas Analysis

Power transformers fault diagnosis systems includes specific measurements regarding: the water in oil, combustible gas in oil, temperature, gas pressure, insulation properties, partial discharge, acoustic signatures, motor current profiles, bushing leakage, current detection, moisture in insulation, spectral content of shell vibration, and load current and voltage [7].

The main gases formed as a consequence of electrical and thermal faults in power transformers and evaluated by dissolved gas results are H_2, CH_4, C_2H_2, C_2H_4, C_2H_6, CO_2, and CO, whose relative concentrations depend upon the fault type. A general rule, based on thermodynamic considerations, is that the degree of chemical unsaturation of the gases formed is related to the energy density of fault [8].

So far as sufficient field knowledge and expert system arrangements, the above mentioned model can be used for power transformer fault diagnosis. An overview of fault diagnosis techniques used to evaluate the power transformer functioning based on specific measurements is given below. Depending upon dissolved gas consequences and injunctive test consequences, the fault diagnosis model in transformer oil has been establish, as shown in figure 3. Where: the meaning of place (p) as shown in table 1.

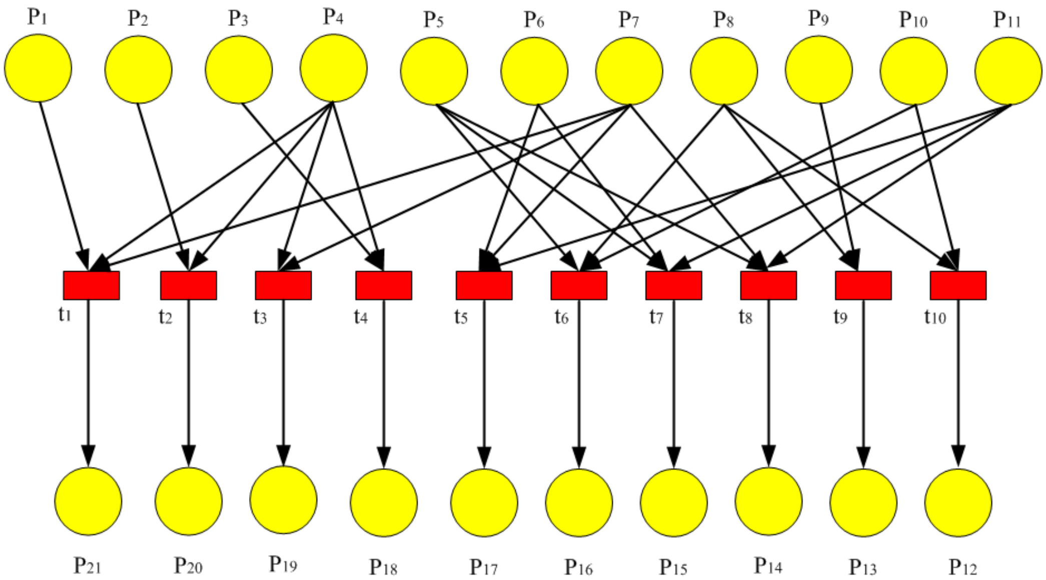

Figure 3. Fault diagnosis model in transformer oil

Table 1. The definition of the places

Place number	Meaning
P_1	Core to ground insulation resistance drops
P_2	Core current abnormity
P_3	Winding alternative current resistance
P_4	Dissolved gas results overheat
P_5	Co_2, Co content increases and Ø(Co_2) / Ø(Co) oversize
P_6	Overproof direct current creepage
P_7	Three-phase idling abnormity
P_8	Partial discharge
P_9	Spark discharge
P_{10}	Discharging of low energy
P_{11}	Discharging of high energy
P_{12}	Oil partial discharge
P_{13}	Insulating aging, insulation puncture
P_{14}	Interturn short circuit
P_{15}	Grounded short circuit
P_{16}	Dendritic leakage in insulating paper
P_{17}	Insulating aging, lead poor contacts
P_{18}	Faults of coil
P_{19}	Poor contact of core
P_{20}	Flux leakage
P_{21}	Iron-core plural earth

4. Illustrative Diagnosis Samples and Results

In this section, the relation between dissolved gas results and power transformer faults are analyzed. The five samples data are shown in table 2.

Table 2. The five samples data

Name (μL/L)	Contents Sample 1	Contents Sample 2	Contents Sample 3	Contents Sample 4	Contents Sample 5
Hydrogen (H_2)	123	369	37	192	871
Nitrogen (N_2)	44454	62720	60004	65954	60882
Carbon (CO)	74	752	638	117	1694
Carbon dioxide (CO_2)	650	3178	1959	1209	1529
Methane (CH_4)	314	89	254	39	263
Acetylene (C_2H_2)	42	31	48	62	513
Ethylene (C_2H_4)	756	397	238	42	284
Ethane (C_2H_6)	216	193	177	3	18

Sample 1: The dissolved gas result data of a main transformer (AEG-ETI 30827) investigated in a Mudurnu substation, March 24th 2012. Diagnosing result: overheating fault and ratio between CO and CO_2 is normal. Test results: the phase A current resistance of high voltage winding is infinity, insulation ground resistance, core current, alternative current leakage, three phase idling and other data are normal. Owing to the petri nets power transformer fault diagnosis model, it is provide that:

$$
A^{-}=\begin{array}{c} \\ t_1\\ t_2\\ t_3\\ t_4\\ t_5\\ t_6\\ t_7\\ t_8\\ t_9\\ t_{10} \end{array}
\begin{bmatrix}
P_1 & P_2 & P_3 & P_4 & P_5 & P_6 & P_7 & P_8 & P_9 & P_{10} & P_{11} & P_{12} & P_{13} & P_{14} & P_{15} & P_{16} & P_{17} & P_{18} & P_{19} & P_{20} & P_{21}\\
0&0&0&0&0&0&0&0&0&0&0&1&0&0&0&0&0&0&0&0&0\\
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0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1&0\\
0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&1
\end{bmatrix}
$$

$$
A^{+}=\begin{array}{c} \\ t_1\\ t_2\\ t_3\\ t_4\\ t_5\\ t_6\\ t_7\\ t_8\\ t_9\\ t_{10} \end{array}
\begin{bmatrix}
P_1 & P_2 & P_3 & P_4 & P_5 & P_6 & P_7 & P_8 & P_9 & P_{10} & P_{11} & P_{12} & P_{13} & P_{14} & P_{15} & P_{16} & P_{17} & P_{18} & P_{19} & P_{20} & P_{21}\\
0&1&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0\\
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0&0&0&0&0&0&0&1&0&1&1&0&0&0&0&0&0&0&0&0&0
\end{bmatrix}
$$

$A = A^{-}-A^{+}$

Result from initial situations: M_0 = [0 0 0 0 0 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0] the corresponding P_{20} fault is flux leakage. On position, later the lid is hanged, it is appeared that the flux leakage of the phase A non-exhorting tap switch 3th rank has been burned truly, which matches the consequence designated by the petri nets.

Sample 2: The dissolved gas result data of a main transformer (Elektro Putere 97037) investigated in a Sakarya substation, May 13th 2012. Dissolved gas diagnosing result: overheating fault. Injunctive tests results: the core resistance to ground is 0, ground current 8.7 A > 0.5 A, and other results data are normal. Result from initial situations: M_0 =[0 0 0 0 0 0 0 1 0 1 1 0 0 0 0 0 0 0 0 0 0]. After above inferring: M = [0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1]. The corresponding P_{21} fault is iron-core plural earth. On position, later the lid is hanged, it is discovered that due to the over-length of the tablet to earth, the core is shorten about eight percentages to lead to core plural earth.

Sample 3: The dissolved gas result data of a main transformer (ABB GT-008-93) investigated in a Osmanca substation, June 11th 2012. Dissolved gas diagnosing result: overheating fault. Injunctive tests results: three-phase idling abnormity, CO_2, CO content increases and Ø(CO_2) / Ø(CO) oversize, discharging of high energy and other data are normal. The corresponding P_{14} fault is interterm short circuit. On position, later the lid is hanged, it is founded that due to coil faults include bare metal overheating.

Sample 4: The dissolved gas result data of a main transformer (ESAS GT-015-89) investigated in a Izmit Gis substation, April 19th 2012. Dissolved gas diagnosing result: high energy discharging, injunctive tests results: partial discharge, discharging of low energy and other data are normal. The corresponding P_{12} fault is oil partial discharge. On position, later the lid is hanged; it is appeared that due to insulation aging - insulation puncture.

Sample 5: The dissolved gas result data of a main transformer (ABB GT-019-99) investigated in a Küçükbakkalköy substation, October 31th 2013. Dissolved gas diagnosing result: overheating fault, and low energy discharging. Injunctive tests results: alternative current creep age, three-phase idling abnormity, and discharging of high energy and other data are normal. The corresponding P_{17} fault is insulating aging-lead poor contacts. On position, later the lid is hanged, it is discovered that due to core to ground insulation resistance drops.

5. Conclusions

In this paper, the petri nets technology advanced has been successfully used for the diagnosis of several power transformers in Turkey. It has been proved that using the diagnosis method, more detailed information about the faults inside a power transformer can be obtained. So far as the probing from the advance of artificial neural network and expert system, and based on a further study, I have establish the power transformer fault diagnosis model. The forms of the model based on the petri nets;

1) The petri nets model have the good learning skill. The novel probing and the novel fault type may be joined conveniently. The affluent field knowledge the more certain the diagnosis consequence is. Having the matrix model is convenient for constructing smart power transformer fault diagnosis system and for computer programming.
2) The petri nets model unities the dissolved gas result data and injunctive data with fault cases. It is not only to designate the fault characteristic but also to fix the fault situation.

In recent years, I have advanced a power transformer fault diagnosis system that based on the petri nets, which is agreeing a novel diagnosis instrument. This system can conclude power transformer fault efficiently. It can increase the reliable process and economic productivity of the power transformer. This system needs regular adjustment, regular detection, regular thoroughness and regular supervision in applications.

Acknowledgements

The author is pleased to thank the Turkish Electricity Transmission Company for its cooperation in this research work.

References

[1]. Lin, C.E., Ling, J.M., Huang, C.L., An expert system for transformer fault diagnosis and maintenance using dissolved gas analysis, **IEEE Transactions on Power Delivery,** 8(1), 231-238, (1993).

[2]. Pamuk, N., Uyaroglu, Y., Fault section estimation of electric energy systems using petri nets, **6th International Ege Energy Symposium and Exhibition,** Izmir, Turkey, 608-616, (2012).

[3]. Huang, Y.C., Huang, C.M., Liao, C.C., Chen, J.F., Yang, H.T., A new intelligent fast petri-net model for fault section estimation of distribution systems, **International Conference on Power System Technology,** Perth, Australia, 217-222, (2000).

[4]. Lee, J., Pan, J.I., Kuo, J.Y., Verifying scenarios with time petri-nets, **Information and Software Technology,** 43(13), 769-781, (2001).

[5]. Hadjicostis, C.N., Verghese, G.C., Power system monitoring using petri net embeddings, **IEE Proc. C. Generation Transmission and Distribution,** 147, 299-303, (2000).

[6]. Murata, T., Petri nets: properties, analysis and applications, **Proceeding of the IEEE,** 77(4), 541-580, (1989).

[7]. Su, Q., Mi, C., Lai, L.L., Austin, P., A fuzzy dissolved gas analysis method for the diagnosis of multiple incipient faults in a transformer, **IEEE Transactions on Power Systems,** 15(2), 593-598, (2000).

[8]. Guardado, J.L., Naredo, J.L., Moreno, P., Fuerte, C.R., A comparative study of neural network efficiency in power transformers diagnosis using dissolved gas analysis, **IEEE Transactions on Power Delivery,** 16(4), 643-647, (2001).