PETRI NET BASED TRANSFORMER FAULT DIAGNOSIS

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ABSTRACT

The reduction of the time needed for transformer fault diagnosis is an important task for transformer users. In this paper, Petri Nets are exploited, in order to simulate the transformer fault diagnosis process and to define the actions followed to repair the transformer.

1. INTRODUCTION

Power system reliability depends on components reliability. As the ultimate element in the electricity supply chain, the distribution transformer is one of the most widespread apparatus in electric power systems. During their operation, transformers are subjected to many external electrical stresses from both the upstream and downstream network. As a result, various types of faults (e.g. insulation failure, overloading, oil leakage, short-circuit, etc) can occur to the transformers of an electric utility. The consequences of transformer fault can be significant (damage, oil pollution, etc). Failure of these transformers is very costly to both the electrical utilities and their customers.

When a transformer fault occurs, it is important to identify the fault type and to minimize the time needed for transformer repair, especially in cases where the continuity of supply is crucial. Consequently, it should not come as a surprise that transformer fault diagnosis forms a subject of a permanent research effort.

Various transformer fault diagnosis techniques have been proposed in the literature, for different types of faults [1]. For thermal related faults, the most important diagnostic method is the gas-in-oil analysis, while other methods such as the degree of polymerization, the furanic compounds analysis and the thermography are also applicable. For dielectric related faults, it is necessary to localize and to characterize the partial discharge source, in order to give a correct diagnosis after receiving an alarm signal via sensors or via gas-in-oil sampling. For mechanical related faults, the frequency response analysis and the leakage inductance methods are the more frequently used transformer fault diagnosis techniques. Finally, for transformer general degradation, the dielectric response, the oil analysis and the furanic compounds analysis methods are applicable.

In spite of the wide range of the transformer fault diagnosis methods, the diagnostic criteria developed till today are not fully applicable to all faulty cases, and consequently, the experience of experts still play an important role in the diagnosis of the transformer faults. Dismantling the suspected transformers, performing internal examinations, and holding a group discussion are usually the procedure to conclude the diagnosis.

Expert systems and artificial intelligence techniques have already been proposed to understand the obvious and non-obvious relationships between transformer failures and the causes of failures (i.e. internal or external causes). Preliminary results, obtained from the application of these techniques, are encouraging, however some limitations exist [2]. Knowledge acquisition, knowledge representation and maintenance of a great number of rules in the expert systems require plenty of efforts.

In this paper, Petri Nets are proposed for modeling of transformer fault diagnosis process. Petri Nets are both a mathematical and graphical tool capable of capturing deterministic or stochastic system behavior and modeling phenomena such as sequentialism, parallelism, asynchronous behavior, conflicts, resource sharing and mutual exclusion. The proposed method offers significant advantages such as systematical determination of the sequence of fault diagnosis and repair actions, visual representation of the above actions, as well as estimation of the time needed for transformer repair.

The paper is organized as follows: Section 2 describes the Petri Nets methodology. The application of Petri Nets to transformer fault diagnosis and the obtained results are described in Section 3. Finally, Section 4 concludes the paper.

2. OVERVIEW OF PETRI NETS

Petri Nets (PNs) were introduced in Carl A. Petri's 1962 Ph.D. dissertation. Since that time, they have proved to be a valuable graphical and mathematical modeling tool applicable to many systems. As a graphical tool, PNs can be used as a visual communication aid similar to flow charts, block diagrams, and networks. As a mathematical tool, it is possible to set up state equations, algebraic equations, and other mathematical models governing the behavior of systems.

A PN is a particular kind of directed graph, together with an initial marking, M_0. The underlying graph of a PN is a directed, weighted, bipartite graph consisting of two kinds of nodes, called places and transitions, where arcs are either from a place to a transition or from a transition to a place. In graphical representation, places are drawn as circles, and transitions as either bars or boxes. If a marking (state) assigns to each place p a nonnegative integer k, it is called that p is marked with k tokens. Pictorially, k black dots (tokens) are placed in p.

Places are used to describe possible local system rates, named conditions or situations. Transitions are used to describe events that may modify the system state. Arcs specify the relation between local states and events in two ways: they indicate the local state in which the event can occur, and the local state transformations induced by the event.

The presence of a token in a place is interpreted as holding the truth of the condition associated with the place. The only execution rule in a PN is the rule for transition enabling and firing. A transition t is considered as enabled if each input place p of t is marked with at least $w(p,t)$ tokens, where $w(p,t)$ is the weight of the arc from p to t. An enabled transition may or may not fire. A firing of an enabled transition t removes $w(p,t)$ tokens from all its input places p, and adds $w(p,t)$ tokens to each of its output places, where $w(t,p)$ is the weight of the arc from t to p. The movement of tokens through the PN graph represents the flow of information or control in the system.

For problems that include the completion of an activity, it is necessary and useful to introduce time delays associated with transitions (activity executions) in their net models. Such a PN model is known as a deterministic timed net if the delays are deterministically given, or as a stochastic net, if the delays are probabilistically specified. In both cases, boxes of thick bars graphically represent transitions. The Stochastic Petri Net (SPN) model provides a more realistic representation of matter. In SPNs transitions are associated with random variables that express the delay from enabling to the firing of the transition. The type of distribution in random variables can be uniform, exponential, etc.

3. FAULT DIAGNOSIS USING PETRI NETS

This paper simulates the actions that are followed by the transformer maintenance personnel in order to diagnose the fault and repair the transformer. It is important to notice that the maintenance staff is not able to know the exact problem from the beginning of the diagnosis process; there is crucial information that is obtained during the whole tranformer fault diagnosis process.

To better model the transformer fault diagnosis process, stochastic PNs are used in this paper. These nets provide a structural tool, like flow charts, with the additional advantages of simulating dynamic and concurrent actions, and they provide the simulation results using stochastic times for a number of transitions.

Fig. 1 presents the proposed PN model for transformer fault diagnosis, Fig. 2 shows the "not on-site repair" subnet (i.e. in case that the transformer repair is implemented in the factory), and Table 1 describes all places and transitions that constitute the PN models of Fig. 1 and 2. Places in shadow boxes represent the crucial information that is obtained during the transformer fault diagnosis process; these places represent two opposite events, so tokens can be placed only in one of the places.

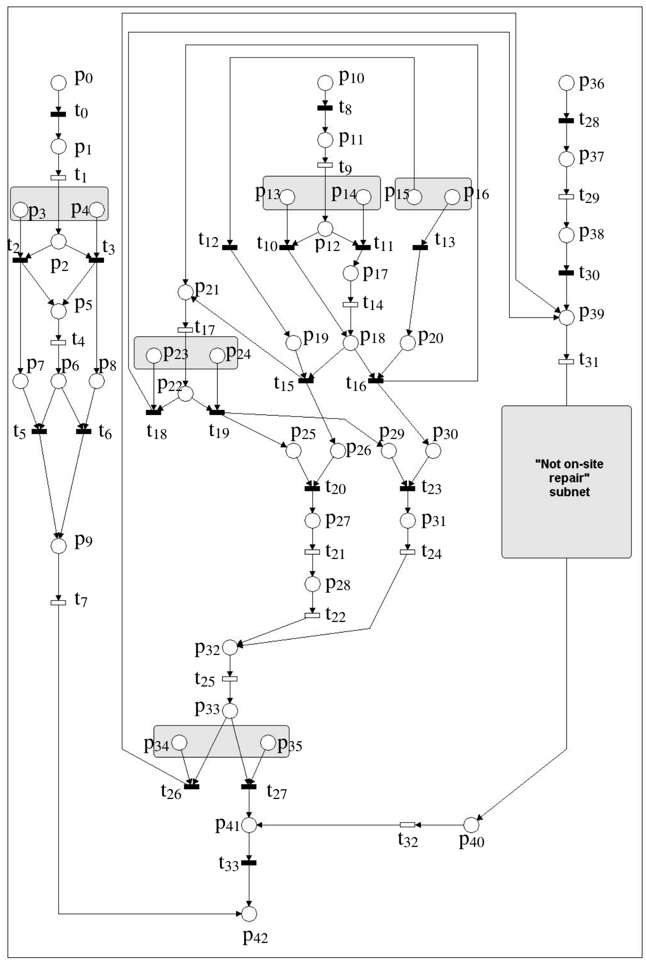

Fig. 1: PN model for transformer fault diagnosis.

The proposed PN models the following transformer faults: overloading, short-circuit, insulation failure and oil leakage. The protection equipment that is used in a typical distribution transformer for fault detection is the oil thermometer and the Buchholz relay. These protecting schemes may be alarmed or tripped with the appearance of a problem, and when this happens there is an immediate warning to the personnel. The possible initial warnings are a) alarm of the oil thermometer (oil thermometer cannot trip without earlier alarm), and b) alarm or trip of the Buchholz relay. In case of alarm, it can be a change to trip when the maintenance staff arrives to the transformer, depending on problem's seriousness and the time required arriving in transformer's area.

	Description of places and transitions	Duration (hours)		Description of places and transitions	Duration (hours)
Main Petri net					
p_0	Oil thermometer alarms		t_{17}	Transformer is checked	1
t_0	Alarm is activated	0	p_{22}	Is it possible repair fault on the spot?	
p_1	Personnel is notified		p_{23}	It is not possible to repair	
t_1	Personnel is moving to transformer area	[0 2]	t_{18}	Fault cannot be repaired on the spot	0
p_2	Existence of alarm or trip?		p_{24}	It is possible to repair	
p_3	Oil thermometer still alarms		t_{19}	Fault can be repaired on the spot	0
t_2	Alarm is still activated	0	p_{25}	Possibility for repairing oil leakage	
p_4	Oil thermometer tripped		p_{26}	Problem of oil leakage	
t_3	Trip is activated	0	t_{20}	Repair of oil leakage is possible	0
p_5	Need to check the loads		p_{27}	Personnel prepares to repair transformer	
t_4	Loads are checked	[1 5]	t_{21}	Transformer is repaired	[2 5]
p_6	Does transformer need to restart?		p_{28}	Lost oil needs to be replaced	
p_7	It doesn't need to restart		t_{22}	Lost oil is replaced	1
t_5	No restart is needed	0	p_{29}	Possibility for repairing insulation failure	
p_8	It needs to restart		p_{30}	Problem of insulation failure	
t_6	Transformer is restarting	0	t_{23}	Repair of insulation failure is possible	0
p_9	Loads have to be reduced properly		p_{31}	Need to replace problematic external parts	
t_7	Loads are reduced properly	[1 3]	t_{24}	Parts are replaced	2
p_{10}	Buchholz relay alarms		p_{32}	Check if everything works properly	
t_8	Alarm is activated	0	t_{25}	Transformer is checked	1
p_{11}	Personnel is notified		p_{33}	Is transformer working properly?	
t_9	Personnel is moving to transformer area	[0 2]	p_{34}	It is not working properly	
p_{12}	Existence of alarm or trip?		t_{26}	Fault still exists	0
p_{13}	Buchholz relay tripped		p_{35}	It is working properly	
t_{10}	Trip is activated	0	t_{27}	Fault is repaired	0
p_{14}	Buchholz relay still alarms		p_{36}	Buchholz relay trips	
t_{11}	Alarm is still activated	0	t_{28}	Trip is activated	0
p_{15}	Low level of oil indicator		p_{37}	Personnel is notified	
t_{12}	Oil volume has reduced	0	t_{29}	Personnel is moving to transformer area	[0 2]
p_{16}	Air bubbles in Buchholz relay's glass		p_{38}	Identification of transformer's fault	
t_{13}	Air bubbles are observed	0	t_{30}	Existence of a powerful short-circuit	0
p_{17}	Transformer needs to stop		p_{39}	Transformer needs to disconnect	
t_{14}	Transformer is stopped	1	t_{31}	Transformer is disconnected	2
p_{18}	Existence of oil leakage or insulation failure?		p_{40}	Transformer arrives in area of installation	
p_{19}	Oil leakage		t_{32}	Transformer is reinstalled	2
t_{15}	Existence of oil leakage	0	p_{41}	Transformer is ready to work	
p_{20}	Insulation failure		t_{33}	Transformer is restarted	0
t_{16}	Existence of insulation failure	0	p_{42}	Transformer reworks properly	
p_{21}	Check for the exact type of fault				
"Not on-site repair" subnet					
p_0	Transformer is sending to repairing area		p_6	Oil has to be added	
t_0	Transformer arrives to repairing area	[2 24]	t_6	Oil is added	4
p_1	Oil has to be removed		p_7	Check for the proper operation	
t_1	Oil is removed	1	t_7	Check is done	1
p_2	Inside search is needed		p_8	Is transformer working properly?	
t_2	Tank is opened	1	p_9	It is not working properly	
p_3	Check for the exact type of fault		t_8	Fault still exists	0
t_3	Check is done	1	p_{10}	It is working properly	
p_4	Identification of fault		t_9	Fault is repaired	0
t_4	Fault is repaired	[72 360]	p_{11}	Transformer is ready to be sent back in its area	
p_5	Transformer has to be reassembled		t_{10}	Transformer is transferred	[2 4]
t_5	Transformer is reassembled	1			

Table 1: Description of PN places and transitions and duration of PN transitions.

When the oil thermometer alarms or trips, there is an overloading problem in the transformer. The maintenance staff has to check if the loads are over the transformer overloading limits, reduce the loads accordingly and restart the transformer (in case of trip).

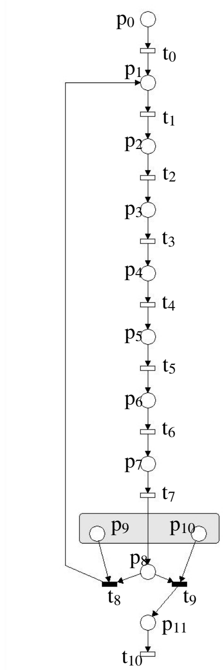

Fig. 2: PN model for the “not on-site repair” subnet

The handling of the maintenance staff is more complex, in case that the Buchholz relay is activated. The possible problems can be short-circuit, insulation failure or oil leakage. On the contrary to the activation of the oil thermometer, the initial warning of the Buchholz relay can be a trip. In this case, the problem is the appearance of a strong short-circuit. The repair of the damage can not be done in the transformer installation area; the transformer must be disconnected and transferred in a dedicated repairing area (e.g. in a transformer factory).

If the initial warning of the Buchholz relay is alarm, then the maintenance staff checks if the relay has been tripped, when they finally arrive in the transformer's area. They also check for the kind of damage. There are two possible contingencies: either the level of the oil indicator is low (p_{15}), or there are air bubbles behind the glass of the Buchholz relay (p_{16}). In the first case, the problem is oil leakage, otherwise there is insulation failure. The operation of transformer stops (in case of alarm) and it is checked if it is possible to repair the transformer on site. This depends on a) the type of problem: the repair can be done if the oil leakage is not wide (i.e. the size of hole in the tank is very small) or if the insulation failure is on a part outside the tank, and b) the existence of suitable tools. The capability of on site repair enables repairing possibilities for the two possible problems (p_{25} and p_{29}) and the specific type (p_{26} or p_{30}) enables the transition t_{20} or t_{23}. Then the staff works on the problem (in the case of oil leakage, the lost oil has also to be replaced). Finally, there is a check if everything works right. If there is still a problem, then the transformer must be sent to a dedicated repairing area (i.e. on site repair is not possible). The "not on-site repair" subnet of Fig. 2 is then models the transformer fault diagnosis and repair process.

Fault	Duration (hours)
Oil leakage (without trip)	8
Oil leakage (not on-site repair)	159
Overloading	4
Insulation failure (bushings, without trip)	6
Insulation failure (not on-site repair)	258
Short-circuit (not on-site repair)	275

Table 2: Simulation results

In the proposed PN modeling, immediate, deterministic and stochastic transitions are used, which take integer values that represent hours. For stochastic transitions, uniform distribution is considered. The duration of the transitions depends on the electric utility as well as the manufacturing plant that is in charge for the “not on-site repair” of the transformer. Table 1 presents indicative values for the duration of the transitions of the main Petri Net and the “not on-site repair” subnet. In Table 1, the duration of the immediate transitions is zero hours, the duration of the deterministic transitions is a positive integer number of hours and the duration of the stochastic transitions can take an integer value of hours from the interval that is specified by two integer numbers into square brackets. Table 2 presents the simulation results for fault diagnosis and repair using the main Petri Net and the “not on-site repair” subnet models as well as the duration of the transitions shown in Table 1. The heavy impact of the “not on-site repair” on the duration of the transformer repair is obvious, when analyzing the results of Table 2.

4. CONCLUSIONS

Transformer fault diagnosis and repair is a complex task that includes many possible types of faults and demands special trained personnel. This paper is concentrated on the investigation of the applicability of Stochastic Petri Nets in the modeling of transformer fault diagnosis and repair process. Simulation results for the most common types of transformer faults (overloading, oil leakage, short-circuit and insulation failure) are presented. The proposed methodology provides a systematical determination of the sequence of fault diagnosis and repair actions and aims at estimating the duration for transformer repair.

5. REFERENCES

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