EXPERT SYSTEM FOR POWER TRANSFORMER DIAGNOSIS

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ABSTRACT

The power transformers are essential equipment in all transport and distribution grids. Minor faults or defects of this equipment can lead to ravaging effects.
The most part of the monitoring and diagnosis systems are developed around expert systems. The expert systems regroup the methods based on analytical models and the ones based on knowledge on the system.
The paper deals with a diagnosis system dedicated to the power transformers. Based on the effects noted in the behavior of the power transformers, an expert system for the diagnosis and the functional testing was developed, by considering the abnormal comportments and the faults which determine these.
For building the inference mechanism, the faults tree method applied to the transformers was used. The database is comprehensive and takes into account the most frequent faults which occur during the transformers operation. The designed expert system was developed by using the CLIPS 6.0 programming medium.
The paper presents the results of the system running and the conclusions resulted after the expert system was executed.

INTRODUCTION

An expert system is a program which uses knowledge and inference procedures for solving quite difficult problems which normally require a human expert for finding the solution. On brief, the expert systems are software which stores dedicated knowledge programmed by the experts for solving problems difficult to be revealed manually.

Characteristics of the expert systems

The expert systems are often used when there are not available clear algorithmic solutions. The main characteristic is the presence of a knowledge database together with a searching algorithm proper with the reasoning type.
Often, the knowledge database is quite large. For this reason it is very important the way how the knowledge is represented.
The knowledge database must be separated by the software which at its turn must be as stable as possible.
The operations of these systems are then controlled by a simple procedure whose nature depends by the knowledge nature.
As different artificial intelligence software, when other techniques are not available, the searching method is used. The different expert systems differ from this point of view (Patterson 1999).

Structure of an expert system

The systems based on knowledge can be applied for any area of knowledge. Expert systems must contain three main modules (Figure 1):
a) The knowledge database is done from the sum of specific knowledge specified by the human expert. The knowledge loaded here is mainly the description of the objects and of the relations between them.
b) The inference devices consist in the sum of the algorithms for determining solutions for the expertise problems, similarly to the human expert.
c) The base of facts (Factual knowledge) contains a dynamic collection of information which changes itself during the call of the expert system. It depends on the practical expertise problem.
Besides these modules, an expert system contains also several modules which offer the ability to communicate with the user and the human expert.
The user interface is the one which performs the dialogue between the user and the system, by using a quasi-natural language. It generally contains the systems of menus and the graphical user interfaces specific to the men-machine communication.
Knowledge acquisition module performs the task of acquiring the specialized knowledge offered by the human expert or by the knowledge engineer. It verifies the validity of the knowledge and generates a knowledge base specific to the expert system.
Explanations module allows tracing the way followed during the ration activity by the expert system. It outputs arguments for the resulted solutions.

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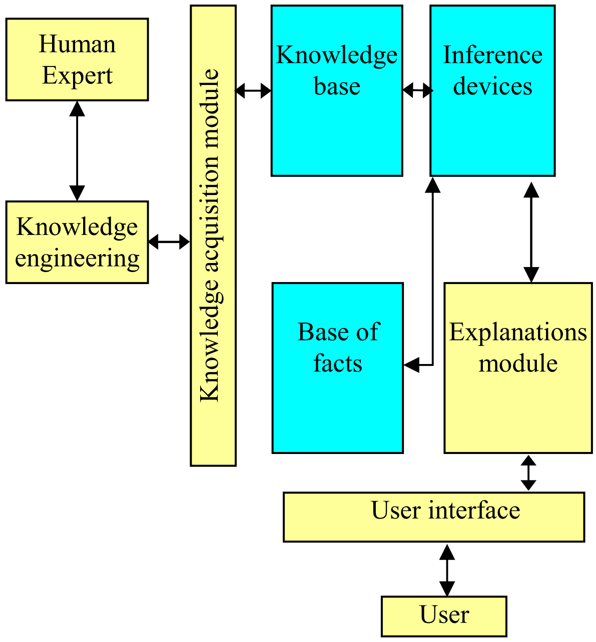


Figure 1: The general structure of an expert system

There are more the formalisms for knowledge representation, the most important being: the first order predicates logic formalism; the production rules formalism; the frames formalism.
In present, the production rules formalism is the most used method for knowledge representation. This formalism is based on the idea that most of the expert information has a structure which is like the natural language, as "if certain premises are fulfilled then some conclusions can be obtained".
A rule consists of an IF part and a THEN part (also called a condition and an action). The IF part, lists a set of conditions in some logical combination. The piece of knowledge represented by the production rule is relevant to the line of reasoning, being developed if the IF part of the rule is satisfied; consequently, the THEN part can be concluded, or its problem-solving action taken. Expert systems whose knowledge is represented in rule form are called rule-based systems.
For presenting the production rules formalism, an expert system from simplifying the truth table of a complex logical circuit was belt up. This is using the most frequently procedures of the language CLIPS. This application indicates how interesting can be integrated the procedures with the rules.

EXPERT SYSTEM FOR DIAGNOSIS OF A POWER TRANSFORMER

The power transformers are the subject of important electric and mechanic stresses during all the operation. These stresses reduce the dielectric rigidity of the insulation system of the transformer. The reduction of the electric rigidity evolves to thermal and electric faults which can determine defects and even transformer destruction. Still in the incipient faults, chemical and physical changes occur within the transformers. These changes can be analyzed in order to get a warning signal on the type of fault which evolves within the transformer. In this way, actions can be performed before the situation gets dangerous.
The expert system used for the diagnosis of the analyzed system is based on the faults tree method.
This method implies to fulfill several steps, as follows: defining the analyzed system; the development of the faults tree of the system; qualitative and quantitative evaluation of the faults tree.
For the proposed system, power transformer respectively, the different faults and their possible causes are analyzed (Popescu et al. 2002), as are presented.
The most five frequent symptoms which occur during the power transformers operations will be analyzed. They are:
a) Symptom S_1: Gases emanation
Causes:
S11: Short circuit between turns;
S12: Overloaded operation.
b) Symptom S_2: Abnormal noises
Causes:
S21: Screw assembling;
S22: Wrong positioning of the jokes on cores;
S23: Wrong fixation of the coils;
S24: Air in the tank and in coils;
S25(S11): Short circuit between turns;
S26: Static discharges or light breakdowns of the insulation.
c) Symptom S_3: Local or general heating
Causes:
S31 (S11): Increased current due to short circuit between turns;
S32: Increased current due to short circuit of the terminals;
S33: Increased current due to short circuit to the core;
S34: Weaken contacts;
S35: Oil saponification;
S36: Weaken magnetic core.
d) Symptom S_4: Protections tripping
Causes:
S41(S11): Short circuit between turns;
S42: Breakdown at one terminal;
S43: Ground fault in the grid;
S44: Short circuit in the grid.
e) Symptom S_5: Oil leakage
Causes:
S51: Points of welding;
S52: Sealing faults.
The development of the faults tree is a laborious step, when the human expert must demonstrate high ability in knowledge and understanding of the analyzed system. The faults tree is developed in a hierarchal manner, starting from the upper level towards the lower levels. The level of detail is given by the requested deep of the analysis.

The faults tree of the expert system corresponding to the power transformer, developed based on the faults and possible causes presented, is depicted in Figures 2 and 3.

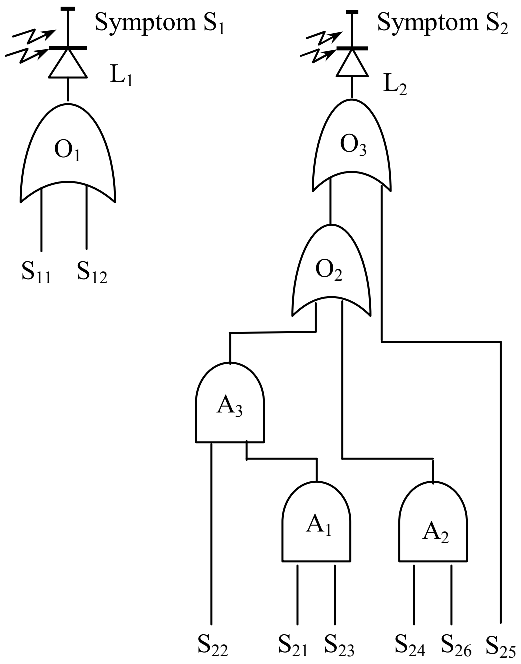


Figure 2: The faults and possible causes for the symptoms S_1 and S_2

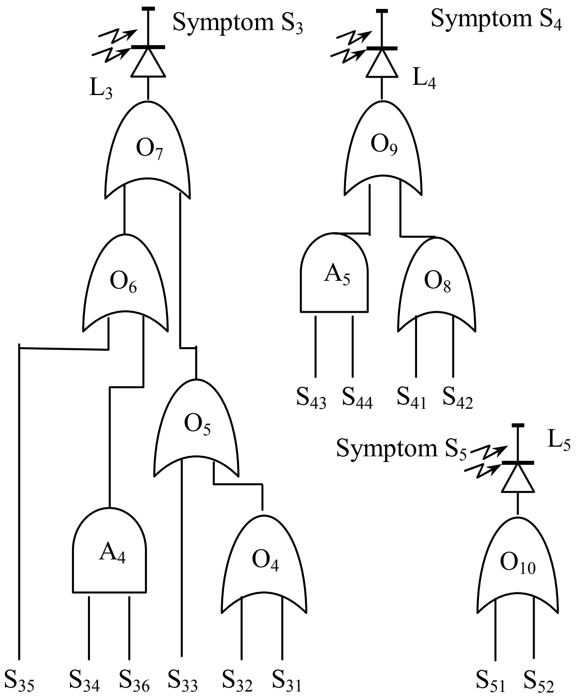


Figure 3: The faults and possible causes for the symptoms S_3, S_4 and S_5

It can be noticed that the same cause can produce different faults, with different symptoms. As example is the fault "Short circuit between turns".

The implementation of the faults tree is performed with logic gates.

Each possible fault which influences the considered critical event is represented by a source. The logic 1 of each source means existence of the corresponding fault.

In order to reduce the true table of the tree corresponding to the considered fault, an expert system was developed, by using the programming language CLIPS (Reference Manual CLIPS 1998).

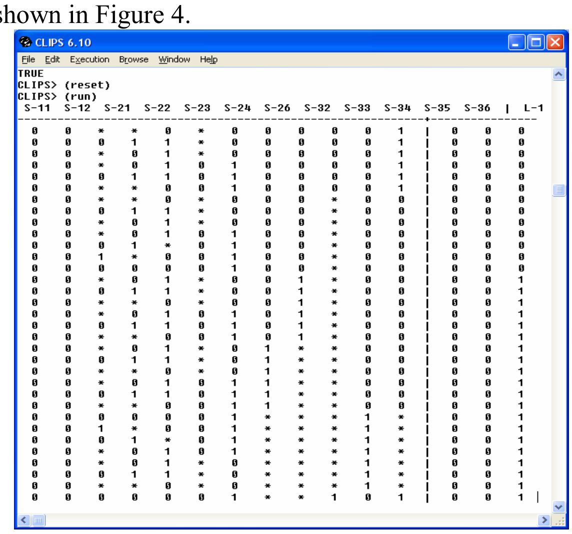
The specific algorithm developed in CLIPS language simplifies the table of truth for a logical complex circuit with more inputs (sources) and outputs.

The simplification procedure implies the following steps:

- the connections between the circuit components are initialized;
- the response of the system when all sources are set to zero is determined;
- a single source is modified and the answer of the system is determined. By using the Gray code, all possible combinations of inputs are iterated. By using the Gray code, only one source is modified at each step, in order to determine the answer in the table of decisions (the use Gray code determines the minimization of the execution time);
- during the determination of the responses, a rule checks if two sets of inputs which are different by a single input determines the same answer. If YES, this single input can be replaced by „*" (it signifies that the value of that input has no importance for obtaining the same answer);
- once that all the answers and the simplifications were determined, the table of decisions of the circuit is printed.

This application exemplifies the use of most usual procedures available within CLIPS software and how interesting can be integrated with the rules.

Considering that the symptoms S1, S2 and S3 occur simultaneously, the causes which produced them can be identified by analyzing the results of the program as is shown in Figure 4.



```
CLIPS 6.10
File  Edit  Execution  Browse  Window  Help
TRUE
CLIPS> (reset)
CLIPS> (run)
 S-11  S-12  S-21  S-22  S-23  S-24  S-26  S-32  S-33  S-34  S-35  S-36  |  L-1
---------------------------------------------------------------------------------
   0     0     *     *     0     *     0     0     0     0     0     1   |   0     0     0
   0     0     0     1     1     *     0     0     0     0     0     1   |   0     0     0
   0     0     *     0     1     *     0     0     0     0     0     1   |   0     0     0
   0     0     *     0     1     0     1     0     0     0     0     1   |   0     0     0
   0     0     0     1     1     0     1     0     0     0     0     1   |   0     0     0
   0     0     *     *     0     0     1     0     0     0     0     1   |   0     0     0
   0     0     *     *     0     *     0     0     0     *     0     0   |   0     0     0
   0     0     0     1     1     *     0     0     0     *     0     0   |   0     0     0
   0     0     *     0     1     *     0     0     0     *     0     0   |   0     0     0
   0     0     *     0     1     0     1     0     0     *     0     0   |   0     0     0
   0     0     0     1     *     0     1     0     0     *     0     0   |   0     0     0
   0     0     1     *     0     0     1     0     0     *     0     0   |   0     0     0
   0     0     0     0     0     0     1     0     0     *     0     0   |   0     0     0
   0     0     *     0     1     *     0     0     1     *     0     0   |   0     0     1
   0     0     0     1     1     *     0     0     1     *     0     0   |   0     0     1
   0     0     *     *     0     *     0     0     1     *     0     0   |   0     0     1
   0     0     *     0     1     0     1     0     1     *     0     0   |   0     0     1
   0     0     0     1     1     0     1     0     1     *     0     0   |   0     0     1
   0     0     *     *     0     0     1     0     1     *     0     0   |   0     0     1
   0     0     *     0     1     *     0     1     *     *     0     0   |   0     0     1
   0     0     0     1     1     *     0     1     *     *     0     0   |   0     0     1
   0     0     *     *     0     *     0     1     *     *     0     0   |   0     0     1
   0     0     *     0     1     0     1     1     *     *     0     0   |   0     0     1
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   0     0     *     *     0     0     1     1     *     *     0     0   |   0     0     1
   0     0     0     0     0     0     1     *     *     *     1     *   |   0     0     1
   0     0     1     *     0     0     1     *     *     *     1     *   |   0     0     1
   0     0     0     1     *     0     1     *     *     *     1     *   |   0     0     1
   0     0     *     0     1     0     1     *     *     *     1     *   |   0     0     1
   0     0     *     0     1     *     0     *     *     *     1     *   |   0     0     1
   0     0     0     1     1     *     0     *     *     *     1     *   |   0     0     1
   0     0     *     *     0     *     0     *     *     *     1     *   |   0     0     1
   0     0     0     0     0     0     1     *     *     1     0     1   |   0     0     1
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Figure 4: The results of the program running for simultaneously symptoms S_1, S_2 and S_3

The results of the program running highlight important simplification of the true table. The 2^{12} (4096) possible combinations are reduced to 160 distinct combinations. For the symptom S4 (Protections tripping) the causes can be identified by analyzing the results in Figure 5.

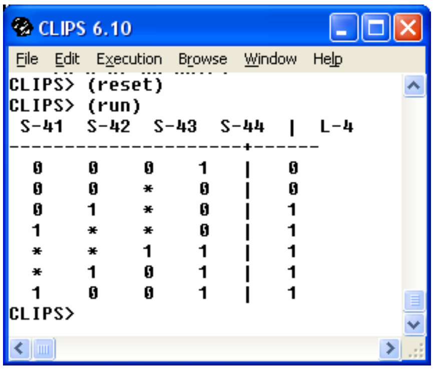

Figure 5: The results of the program running for symptom S_4

If two or more symptoms occur simultaneously, the developed Inference devices can identify very fast the causes which induced the fault. If the information within the Base of facts is considered, the causes can be identified even more precisely.

QUANTITATIVE ANALYSIS OF THE RELIABILITY OF THE POWER TRANSFORMER

The quantitative analysis of the fault tree is the last step in the methodology of reliability analysis of the systems by using the fault tree method. This impose to determine the probability of occurrence of the critical event analyzed, starting from the probabilities of occurrence of the events (faults) and taking into account their propagation ways through the logic gates of the tree.
This methodology imposes to write the structural logic function starting from the fault tree of the analyzed system as::

$$E_{cr} = \Phi_l\left(E_1, E_2, ..., E_i, ...E_n\right) \quad (1)$$

where,
E_{cr} is the critical event of the system, expressed in terms of the primary events Ei (i=1, 2,…,n), considered as independent between them.
Starting from the logic function (1) it can be expressed the algebraic one

$$E_{cr} = \Phi_a\left(E_1, E_2, ..., E_i, ...E_n\right) \quad (2)$$

By taking into account the transformations specified in Table 1, corresponding to the basic logic gates of the fault trees:

Table 1: The transformations of the basic logic gates

Logic gate	Relation	
	logical	Algebraic
AND	$Ei \cap Ej$	$Ei \cdot Ej$
OR	$E_i \cup E_j$	$E_i + E_j - E_i \cdot E_j$

Even the method described above is systematic, it is quite complex because it requires writing and processing the structural function corresponding to the fault tree of the analyzed system. In practice, in order to facilitate the quantitative evaluation, it is possible to avoid the writing of the structural function. In this case, the calculus will be done step by step, from down to up, starting from the basic levels corresponding to the primary events, to the critical event. Following will be presented the relations which allow to highlight the propagation of the tree events by the way of the fundamental logic gates (AND, OR).
For an AND gate with n inputs we have:

$$P(1 \cap 2 \cap ... \cap n) = P(1) \cdot P(2) \cdot ... \cdot P(n) \quad (3)$$

For an OR gate with two inputs we have:

$$P(1 \cup 2) = P(1) + P(2) - P(1) \cdot P(2) \quad (4)$$

For small enough fault probabilities (in practice $P<10^{-2}$, which is quite usual), it can be used the approximate expression:

$$P(1 \cup 2) = P(1) + P(2) \quad (5)$$

The simplified expression (5) can be generalized for an OR gate with n inputs:

$$P(1 \cup 2 \cup ... \cup n) = P(1) + P(2) + ... + P(n) \quad (6)$$

The faults for the symptoms S_4

The fault tree from Figure 4 will be quantitatively evaluated for the symptoms S_4. The probability of occurrence of the event E_{cr} will be estimated, starting from the probabilities of occurrence of the primary events S_{41}, S_{42}, S_{43}, S_{44}. A possible approach is to write the structural logic function corresponding to the tree:

$$E_{cr} = \left[\left(S_{41} \cup S_{42}\right) \cup \left(S_{43} \cap S_{44}\right)\right] \quad (7)$$

For the presented example, thanks to the reduced complexity of the structural function, the probability of occurrence of the critical event can be expressed directly:

$$P\left(E_{cr}\right) = P\left\{\left[\left(S_{41} \cup S_{42}\right) \cup \left(S_{43} \cap S_{44}\right)\right]\right\} \quad (8)$$

It results the algebraic expression corresponding to relation (8):

$$P(S_4)=\{[P(S_{41})+P(S_{42})]+[P(S_{43})\cdot P(S_{44})]\} \quad (9)$$

The faults for symptoms S_3

In order to quantitatively analyze the tree from Figure 3, it is better to avoid writing the structural logic function, because it would be too difficult to process it. The probability of occurrence of the critical event can be evaluated by computing step by step, considering the expressions (3), (5), (6).

This approach is exemplified in Figure 6, where is computed the probability of occurrence of the critical event, staring from the probabilities of occurrence of the primary events. The initial data for the probabilities of the primary events can be obtained from the datasheets of the components.

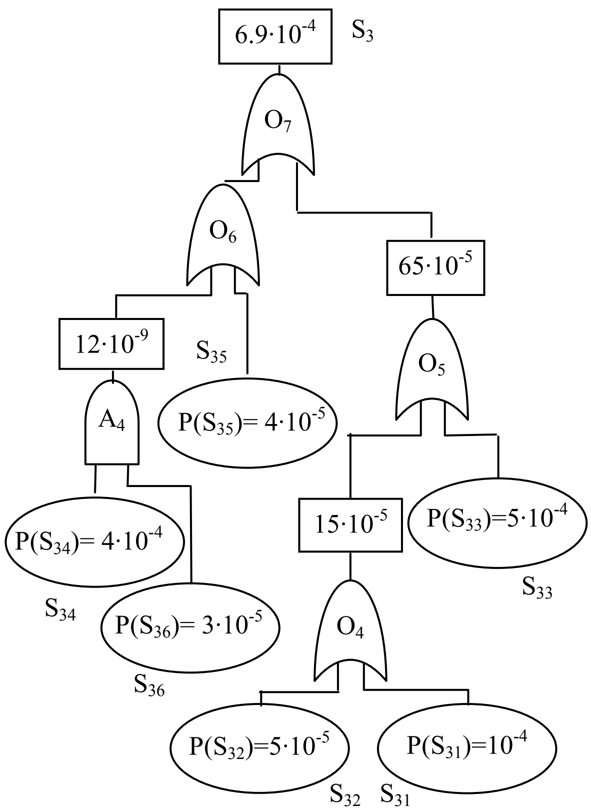

Figure 6: The probability of occurrence of the critical event S_3

CONCLUSIONS

This paper presents an application of the expert systems for the diagnosis of a power transformer. In order to achieve the results, the faults tree method is used.

Taking into account the great number of possible faults (12 sources), the total number of possible combinations being 2^{12} (4096), the expert system performs algorithms difficult to be done manually.

This example shows how the most usual procedures available in CLIPS can be used and how interesting they can be integrated with the rules.

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