PTME – a new expert system application for Power Transformer Troubleshooting and Maintenance

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Abstract: - The scope of this paper is the introduction of PTME (Power Transformer Maintenance Expert), a new expert system application, which can be used as an efficient decision making tool in a sophisticated problem as the optimization of maintenance procedures (preventive, predictive and corrective) of Power Transformers. The expert system comprises a knowledge base and a set of production rules that produce results through the application of forward/backward chaining reasoning. The knowledge base set of data is generally characterized by a complex structure in a tree form, with three main branches that correspond to preventive, diagnostic and corrective maintainance respectively. PTME has been developed at TEI of Athens and can be used both for engineering and educational purposes.

Keywords: - power transformers, maintenance, artificial intelligence techniques, expert systems

1 Introduction

Power Transformers (PTs) are an essential and functionally critical component in Electric Power Systems (EPS). Considering the high reliability and availability requirements in modern EPS, it becomes obvious that critical EPS equipment like PTs should enjoy high quality maintenance, in order to remain in good functional condition and meet the required reliability standards [1, 2]. The introduction of an effective PT Maintenance program is a complex, time-consuming project which requires experienced engineers and may lead to high cost practices [2]. In addition, there is a whole array of tasks that can only be carried out by specialists who have deep understanding of domain problems and the skill to solve them. Since PTs constitute a major device of EPS with high buying and owning cost and wide installed base, there is a great interest in the prevention and diagnosis of damage of PTs, in early stage, via effective troubleshooting and maintainance programs [2, 3, 7-11]. According to these facts, an intelligent system containing as much expert knowledge as possible along with efficient and quick reasoning, would be very helpful to maintenance engineers. In addition, Artificial Intelligence (AI) with Expert System (ES) techniques can provide a significant tool in documenting and representing human expert knowledge [4-8] in this area.

In this context, the objective of this paper is to introduce Power Transformer Maintenance Expert (PTME), a new expert system application that may be a helpful tool in PT troubleshooting and maintenance (preventive, predictive and corrective). Such a tool may also be of great use for teaching and training purposes, as it is continuously available for consultation (one important feature of an expert system is its ability to provide users with an explanation of the reasoning employed to reach a conclusion).

2 PTME application

PTME application comprises a Knowledge Base and a set of Production Rules applied through forward/backward chaining procedures [4, 5]. The Knowledge Base is constructed in a tree form with three main branches corresponding to Preventive, Predictive and Corrective Maintenance (Trouble-shooting) respectively, as shown in Fig. 1.

The expert system interacts with the user through a sequence of selected questions, requiring answers as essential data entry. These data are being processed by the expert system, which finally makes

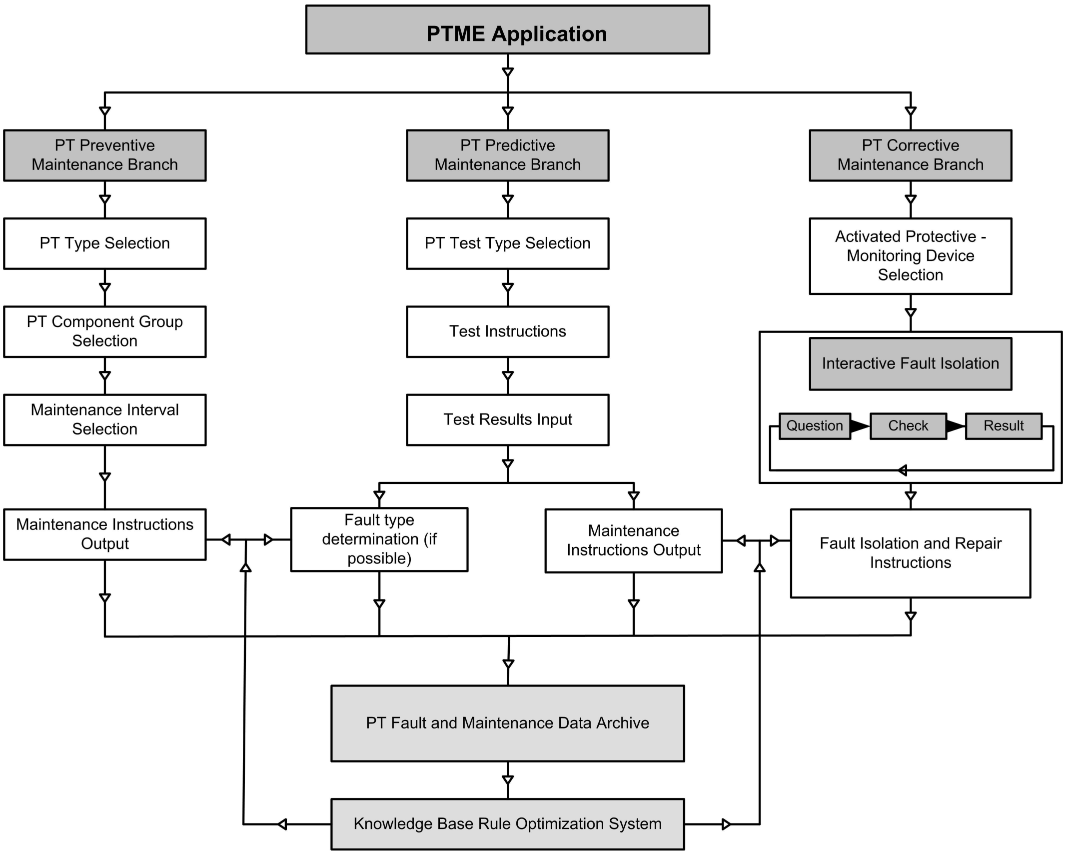

Figure 1. Power Transformer Maintenance Expert (PTME) structure.

suggestions, gives instructions etc., concerning optimum maintenance timetable, localization and type of fault (if possible) or even appropriate repairing actions in order to keep the PT under consideration in good operational condition. In addition, PTME incorporates a, common to all, three branch PT Fault and Maintenance Archive, which keeps records of previous history of each PT and, in cooperation with the Knowledge Base Rule Optimization System, continuously evaluates the system's performance. In case of unsatisfactory results, the system is capable of taking corrective measures, by means of modifying the production rules and changing the sequence of questions made to the user. Moreover, Maintenance Archive information may become useful in clarifying reasons of damage in cases where the system meets difficulty.

A description of PTM-Expert branches follows.

2.1 PT Preventive Maintenance Branch

The scope of PT Preventive Maintenance is repairing or replacement of malfunctioning or aged PT components or subsystems before they completely fail, in order to prevent further damage in the future which may have higher cost or even put the PT completely out of service [2, 10]. In order to achieve this, certain check procedures should be followed, according to a predefined schedule. The preventive maintenance schedule proposed by PTME is based on specific information such as wear-out mechanisms of components, which are vital to ensure continuous PT operation, or records of PT behaviour in the past. PT Preventive Main-tenance Branch involves the following, according to figure 1:

- Selection of the type of PT under consideration (e.g. oil-immersed, dry type).
- Each PT is broken into several groups of components related to a specific task (e.g. cooling system) according to its type. The desired component group should be selected. An example is shown in figure 2.
- Maintenance intervals (weekly, monthly, yearly) should be defined, as in figure 2.
- Specific instructions about necessary actions or measures are given (see figure 3).

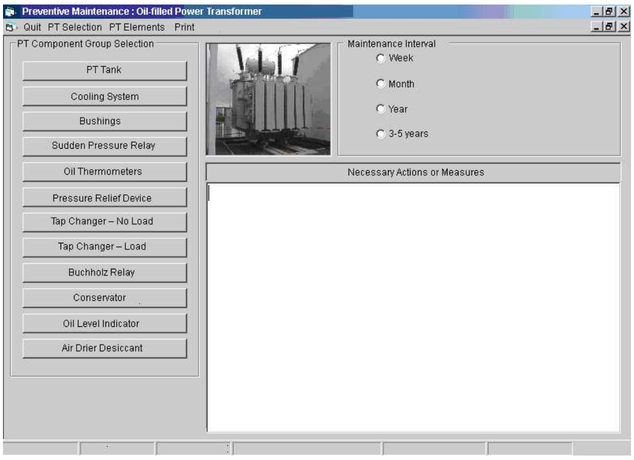

Figure 2. PTME sample screen showing PT component groups and maintenance intervals to be selected.

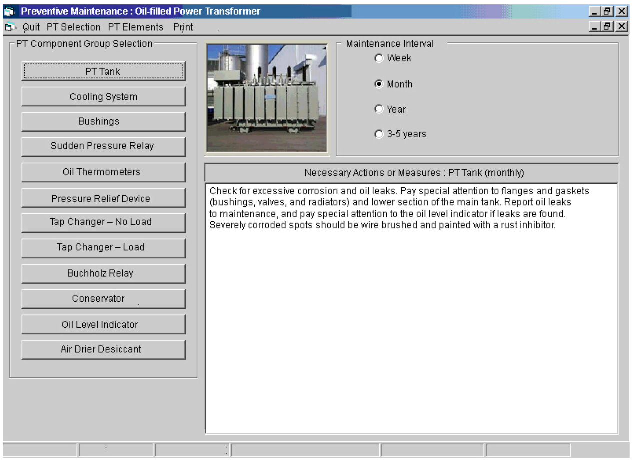

Figure 3. PTME sample screen showing proposed PT tank preventive maintenance actions on monthly basis.

2.2 PT Predictive Maintenance Branch

Predictive Maintenance is based on the determination of a PT's condition through various tests and measurements, which are carried out either during normal operation (on-line tests) or when the PT is out of service (off-line tests). PTME supports various standard non-destructive test procedures such as insulating oil Dissolved Gas Analysis (DGA), physical and chemical parameter specification, winding and core resistance measurements etc., as shown in Table 1 [3, 9-16]. Test results are being processed in order to determine PT condition. Predictive Maintenance Branch operates more efficiently, since maintenance actions are condition-oriented and optimised, in a way to ensure maintenance cost reduction and maximum PT performance.

PT Predictive Maintenance Branch involves the following, according to figure 1:

- Selection of a standard non-destructive test type.
- The user receives detailed test instructions in order to carry out the selected test (if needed).
- The test results are imported into PTME and being processed in order to determine PT condition.
- The system outputs final test analysis reports along with fault type determination (if possible) and the recommended maintenance actions.

Sample screens of PTME results in the case of dissolved gas analysis in a PT, are shown in figures 4 and 5.

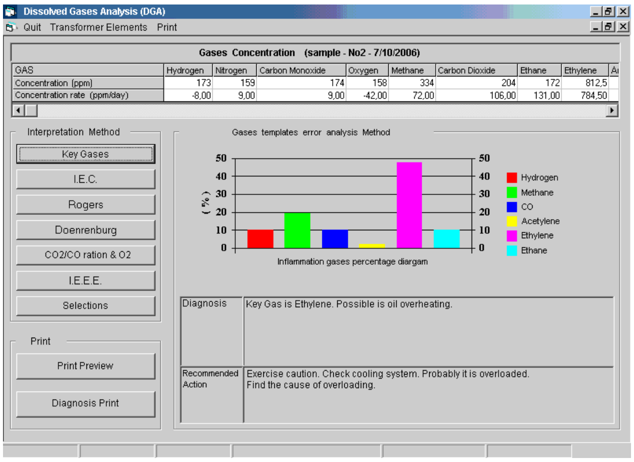

Figure 4. PTME sample screen showing dissolved gas test analysis results according to selected interpretation method (Key Gases).

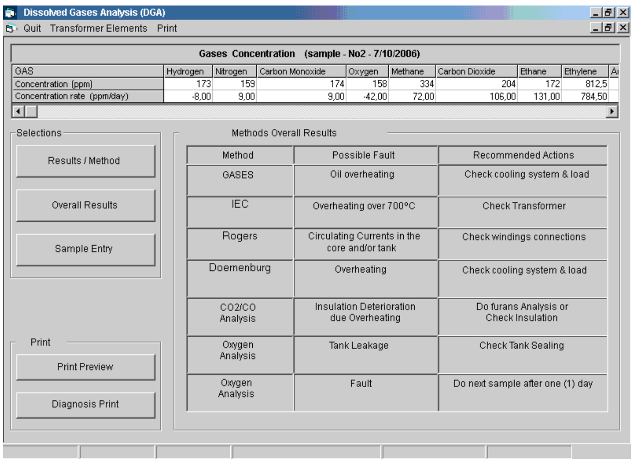

Figure 5. PTME predictive maintenance overall results of dissolved gas analysis in a PT, showing possible fault determination and recommended actions.

Test type	Measures	Detects	Requires
		On-line Tests	
Dissolved Gas Analysis (DGA) [12, 13]	Concentration of dissolved gases in oil such as CH_4, C_2H_2, C_2H_4 etc., or other gases like CO, H_2	Arcing, bad electrical contacts, hot spots, partial discharges, overheating of conductors, oil, tank, cellulose	Laboratory analysis, portable gas-in -oil analyzer
Oil Physical and Chemical tests [14, 15]	Moisture, Interfacial Tension (IFT), acidity, dissolved metals and metal particle count	Insulating oil or paper problems, pump problems etc.	Laboratory analysis
		Off-line Tests	
Turns Ratio, Across Winding Resistance, Winding DC Resistance to Ground and Core Resistance to Ground [16]	Turns ratio change, winding resistance, core resistance	Shorted windings, loose connections, bad contacts, leakage currents, unintentional grounds etc.	Measuring instryments, Wheatstone Bridge, Kelvin Bridge, Megger

Table 1. Standard non-destructive test procedures supported by PTME predictive maintenance branch.

2.3 PT Corrective Maintenance Branch

Corrective maintenance branch proposes the actions that should be taken to restore a failed PT into satisfactory operational condition within the shortest time possible. This usually involves replacement or repairing of specific components that are responsible for the failure. Corrective maintenance is performed at unpredictable intervals because a component's failure can't always be predicted. PTME contains empirical trouble-shooting experience [2, 10, 11] in order to isolate a PT fault through a user-interactive process and provide the required repairing instructions, in order to bring the PT back in service. PT Corrective Maintenance Branch requires the following actions, according to figure 1:

- Selection of the protective or monitoring device /devices that has/have been engaged during the fault.
- Interactive fault isolation through a series of selected questions or suggestions (e.g. indications, checks etc.), as shown in figure 6.
- Final report generation containing suggestions about the required remedial measures (an example is given in figure 7).

2.4 Knowledge aquisition

The acquisition of knowledge needed to achieve the desired levels of performance in an expert system is of great importance. The knowledge required for the PTME application has been acquired from:

- Expert engineers working for years at the Public Power Corporation of Greece and several construction companies at the private sector.
- Data accumulated over the years from engineers working at the power transformer industry.
- Maintenance handbooks and trouble-charts coming from the power transformer industry.

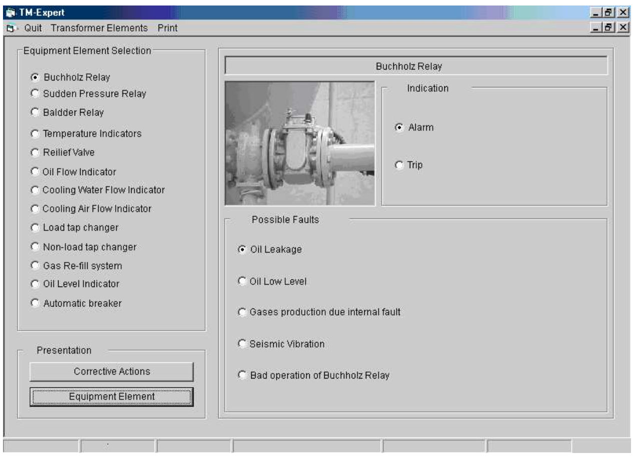

Figure 6. PTME Corrective Maintenance sample screen in the case of an activated alarm of a PT Buchhotlz relay, which implies oil leakage.

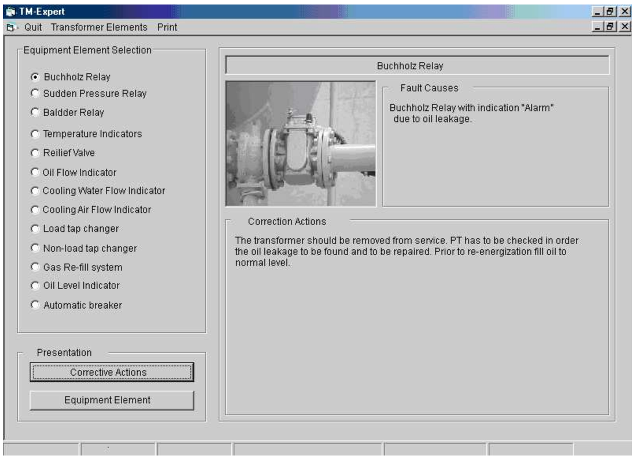

Figure 7. PTME Corrective Maintenance sample screen containing suggestions about the required remedial measures

3 Conclusions

This paper proposes a rule-based expert system (PTME) aiming to manage and optimise Power Transformer Troubleshooting and Maintenance tasks. The system, in its present development state, consists of three main branches, each concerning a particular maintenance category (Preventive, Predictive and Corrective Maintenance). PTME introduces certain advantages:

- Expert knowledge, which is not always easily available at domain, can be encoded in a tree-like structure, easily understood and user-friendly represented.
- Transfer of new knowledge or experience becomes easy because the modification or expansion of the PTESM knowledge base can be carried out in a simple way.

PTME may serve both engineering and educational purposes. Firstly, it is a useful tool in the hands of service engineers or service technicians, in order to achieve efficient PT troubleshooting and maintenance, especially in cases when expert knowledge is not immediately available. On the other hand, PTME may also become useful for training or educational purposes by means of providing a simple tutoring environment that enables skill development, as the user can experiment with hypothetical operational conditions or problems in order to locate possible dependencies and reasons. So PTME could, in some way, “simulate” real practice and help inexperienced technicians familiarize with PT essential troubleshooting and maintenance techniques.

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References:

[1] L.L. Grigsby, *The Electric Power Engineering Handbook*, CRC Press LLC and IEEE Press, 1991.

[2] M. Horning, J. Kelly, S. Myers and R. Stebbins, *Transformer Maintenance Guide, Third Edition*, Transformer Maintenance Institute, S. D. Myers Inc, 2004.

[3] M. Wang, A.J. Vandermaar, K.D. Srivastava *Review of Condition Assessment of Power Transformers in Service*, IEEE Electrical Insulation Magazine, Vol. 18, No 6, 2002, pp. 12-25.

[4] P. Jackson, *Introduction to Expert Systems*, 3rd Edition, Addison-Wesley, 1999.

[5] J. Ignizio, *Introduction to Expert Systems: The Development and Implementation of Rule-Based Expert Systems*, McGraw-Hill, 1991.

[6] Z.Z. Zhang, G.S. Hope, O.P. Malik, *Expert Systems in Electric Power Systems – A Bibliographical Survey*, IEEE Transanctions on Power Systems, Vol. 4, No. 4, 1989, pp. 1355-1362.

[7] Jovelino Falqueto, Matheus Sebastian Telles, *Automatization of the Analysis and Diagnosis in Power Transformers using Artificial Intelligence*, Proceedings of IEEE International Conference on Industrial Informatics, 2006, pp.189-194.

[8] Fu Yang, Zhang Liang, *Comprehensive Method Detecting the Status of the Transformer Based on the Artificial Intelligence*, International Conference on Power System Technology – POWERCON, 2004, pp. 1638-1643.

[9] J. P. van Bolhuis, E. Gulski, and J. J. Smit, *Monitoring and Diagnostic of Transformer Solid Insulation*, IEEE Transactions on Power Delivery, Vol. 17, No. 2, 2002, pp. 528-536.

[10] FIST 3-30, *Transformer Maintenance*, US Depart. Of Interior, Bureau of Reclamation, Denver, Colorado 2000.

[11] FIST 3-31, *Transformer Diagnostics*, US Depart. Of Interior, Bureau of Reclamation, Denver, Colorado, 2003.

[12] IEC 60599, *Mineral Oil-Impregnated Electrical Equipment in Service – Interpretation of Dissolved and Free Gas Analysis*, 1999.
[13] IEEE C57.104, *Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers*, 1991.
[14] ASTM D 1816, *Standard Test Method for Dielectric Breakdown Voltage of Insulating Oils of Petroleum Origin Using VDE Electrodes,* 2004.
[15] ASTM D 971 Rev. A, *Standard Test Method for Interfacial Tension of Oil Against Water by the Ring Method,* 1999.
[16] IEEE 62, *Guide for Diagnostic Field Testing of Electric Power Apparatus – Part 1: Oil-filled Power Transformers, Regulators and Reactors,* 1995.