Electric Power Systems Research 149 (2017) 125–136

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Analysis of artificial intelligence expert systems for power transformer condition monitoring and diagnostics

Mileta Žarković*, Zlatan Stojković

School of Electrical Engineering, University of Belgrade, Bulevar Kralja Aleksandra 73, Belgrade 11020, Serbia

ARTICLE INFO

Article history:
Received 18 October 2016
Received in revised form 9 March 2017
Accepted 22 April 2017

Keywords:
Fault detection
Monitoring
Power transformer
Artificial intelligence
Fuzzy logic
Fault classification

ABSTRACT

A large amount of data is generated through monitoring, maintenance, repair and diagnostics of power transformer. However, all these data cannot preindicate the exact type and probability of failure. To overcome the problem this paper presents artificial intelligence based methodology for power transformers fault detection and classification. The possibility of presented monitoring methodology is to assist the operator's engineers in decision making about urgency of intervention and type of maintenance of power transformer. The article analyzes the application of Mamdani-model and Sugeno-model in fuzzy expert system for fault diagnosis based on the current state of the power transformer. Paper presents two case studies with one unique and five separate controllers. In the first case inputs of controller are results of on-line and off-line transformer tests: age, the overheating temperature of the hot spot, frequency response analysis, temperature of insulation, dissolved gas-in-oil analysis, tgδ and polarization index. Second case study in addition to the existing inputs includes previous measurements. A fuzzy controller (FC) is designed to characterize the operating condition and to determine the urgency of intervention with possibility to indicate probability of specific type of failure. Cumulative probability of occurrence of the faults is also observed in second case study. FCs are tested based on real measurements from Serbian transmission system. The results show acceptable effectiveness in detecting different faults and might serve as a good orientation in the power transformer condition monitoring.

1. Introduction

Power transformer is expensive and an important element in the transmission power system. The condition and proper operation of the transformer directly affect on the transmission power system reliability. The characteristics of the power transformer, which depend on the thermal and mechanical stress, irreversibly change during exploitation as a result of aging. Based on the results of regular tests and on line measurements it is difficult to predict fault and to establish the time frame for the repair, urgency of intervention. Sometimes it is difficult to make decisions about priorities which transformer is necessary to overhaul first. The results of bad decisions are the high cost of repairs and unacceptably long period of unavailability of the transformer. For this it is necessary to make the right decisions about condition based maintenance.

Advanced measurement techniques provide an increasing number of data which need to be processed and used in a smart way. Based on the analysis of these data, many papers [1–7] explain how to monitor the state of power transformer and made overhaul plan. In Ref. [4] are formulated the model for calculation of expected failure repair cost and the model for calculation of load curtailment cost. Paper [5] explains method for determining optimal power transformers exploitation strategy but shows that it is necessary to apply a multitude of different methods and advance techniques. Artificial neural networks (ANN) are used for conditions diagnostic of power transformer in papers [3,6]. Paper [7] uses ANN for transformer fault diagnosis using dissolved gas-in-oil analysis (DGA) and papers [8,9] described approaches for fault classification based on protection signals. Each paper that develops ANN need data base with clearly known outputs and papers [10,11] use EMTP for creation of that database. Cortez in paper [12] present an intelligent system based on cognitive systems for fault prognosis in power transformers. Support vector machine (SVM) is used in papers [13,14] for same purpose.

Fuzzy logic (FL) as part of the artificial intelligence is rarely used in the works, and offers the possibility of applying expert knowledge about the diagnosis of failure. FL is suitable for making a decision about maintenance of power transformer. There are not papers which detect fault of power transformer on the basis of several measured parameters, and FL allows us exactly that.

* Corresponding author. Fax: +381 113248681.
E-mail addresses: mileta@etf.rs (M. Žarković), zstojkovic@etf.rs (Z. Stojković).

http://dx.doi.org/10.1016/j.epsr.2017.04.025
0378-7796/

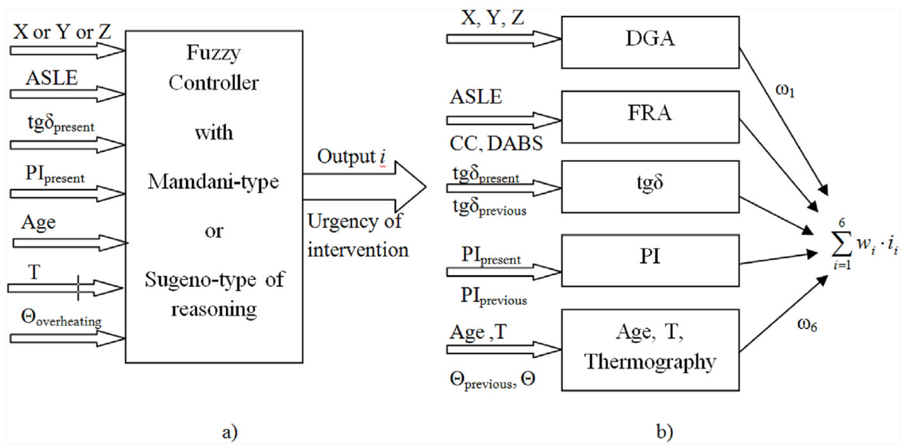

Fig. 1. Artificial intelligence controllers for power transformer fault detection (a) first case study with one controller (b) second case study with five controllers.

Also FL is not used for fault classification yet. Measuring methods whose results are used as controller inputs are thermography, dissolved gas analysis, frequency response analysis. Also controller takes into account age of the element, temperature of insulation, tgδ and polarization index. None of these input parameters for itself cannot clearly indicate malfunction and the urgency of intervention. Because of that this paper shows how to form multiparametric expert systems, FC. There is not a paper that compares other parameters and takes into account the life span of transformer. Limit parameter values from standard do not take into account lifetime of transformer. For this reason FL is used in order to overview the objective and realistic state of power transformers. Sensitivity analysis for creation of FC is presented. For each input and output is selected shape of membership functions (MF) in accordance with values from standards. The rule base has been designed from databases which are formed by large number of measurements from Serbian transmission system. Mamdani-type and Sugeno-type of FL are formed and tested in order to get the best possible solution of problem. One part of presented methodology takes into account previous measured values of parameters. On that way methodology like this is considered a power transformer past. The output information is the urgency of intervention which is actually the probability of failure. Output is connected and indicates the class of power transformer faults. This process is time consuming and requires a good experience about the system behavior, since careful adjusting steps must be effectuated to avoid bad decision and damages of power transformer. Each FC is applied on examples from Serbian transmission system. Results are compared and validated.

2. Multiparametric methodology for power transformer fault detection and classification

Monitoring systems for power transformer detect changes in insulation system in the form of an early warning system, due to thermal/dielectric/chemical or mechanical impact. Monitoring follow measured parameters required for proper operation of power transformer, and diagnostics compare values of these parameters with reference values. Based on this comparison and the values of the parameters in the past it is possible to detect fault or determined progression of pre-existing defect of power transformer. Based on this principle in this paper a FL is used to create fuzzy expert systems. On this way it can be detected: hotspots, degradation of the insulation, localized moisture in insulation and partial discharges and chemical or thermal aging [5]. None of these defects can be detected by a single diagnostic procedure and it is necessary to apply a multitude of different methods in order to enable a trend analysis and condition assessment. Because of that artificial intelligence is used to create multiparametric FCs for condition monitoring and diagnostics of power transformer. FL is good to be applied for managing and implementing human heuristic knowledge about how to make proper decisions when situation is complicated and measuring methods give different, not clearly results. One of the most important qualities of FL is its ability to express the degree of uncertainty in a person's thinking and his subjectivity. MATLAB® technical computing software has been used to design the two FCs with different type of reasoning and conclusion. The layouts of the performed controllers are displayed in Fig. 1. The first case study includes the most important indicator of testing measurements. Fig. 1a presents controller which can be with Mamdani-type and Sugeno-type of reasoning. The second case study presented a combination of multiple controllers that conclude separate results that create one final output Fig. 1b. In second case all indicator of methods are included and on that way fuzziness is increased. Second case study take into account previous measured values of parameters. On that way methodology like this considered power transformer past. Each output *i* ("intervention") can get the weight factor ω_i and thus favoring one of the measuring methods.

Output of both case studies is number from interval 0 to 1. That number presents the probability of failure which indicate on urgency of intervention. Results of both case studies should be compared and analyzed. Results are similar and based on them proposed methodology could classify fault type. The proposed methodology algorithm is shown on Fig. 2. For different manufacturers some parameters and characteristics of transformer may slightly deviate from the usual values. In that case it is need to make changes in the formation of FCs. Because of that, detail explanation of FC formation is represented in next section. Fig. 2 also explains process of FL applying.

3. Implementation of fuzzy logic

The first step in applying FL is fuzzification which simply modifies the input signals, so that they can be properly interpreted and compared with the rules in the rule base. The inputs signals are converted into appropriate fuzzy shape by the MFs. MFs map the degree of the truth claims and classified inputs variables as the linguistic value. Measurements of testing methods are related to the standard condition tests through MFs and entered in the FCs.