Electrical Power and Energy Systems 67 (2015) 324–335

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Design and evaluation of a hybrid system for detection and prediction of faults in electrical transformers

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ARTICLE INFO

Article history:
Received 17 May 2014
Received in revised form 4 November 2014
Accepted 1 December 2014
Available online 18 December 2014

Keywords:
Dissolved Gas-in-oil Analysis (DGA)
Electrical transformer
Fault detection
Fault prediction
Genetic algorithm
Neural network

ABSTRACT

Transformers are the vital parts of an electrical grid system. A faulty transformer can destabilize the electrical supply along with the other devices of the transmission system. Due to its significant role in the system, a transformer has to be free from faults and irregularities. Dissolved Gas-in-oil Analysis (DGA) is a method that helps in diagnosing the faults present in an electrical transformer. This paper proposes a hybrid system based on Genetic Neural Computing (GNC) for analyzing and interpreting the data derived from the concentration of the dissolved gases. It is further analyzed and clustered into four subsets according to the standard C57.104 defined by IEEE using genetic algorithm (GA). The clustered data is fed to the neural network that is used to predict the different types of faults present in the transformers. The hybrid system generates the necessary decision rules to assist the system's operator in identifying the exact fault in the transformer and its fault status. This analysis would then be helpful in performing the required maintenance check and plan for repairs.

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Introduction

A transformer is one of the most crucial element of an Electrical Power Transmission System (EPTS). A fault in the transformer can introduce major problems for the consumers as well as for the maintenance engineers. Many incidents have taken place in the past few years that greatly disrupted the electrical transmission system. One such catastrophe occurred in New Jersey, USA, in December 2013, where, approximately 12,000 people lost their power supply due to a fault in the transformer [10]. Another major incident took place on February 2014 in Stamford, USA, where a transformer caught fire rendering more than 1000 people without light for days [20]. In the year 2000, a disastrous loss was reported at another power plant, where a $86 million US dollars business was interrupted due to a faulty transformer [12].

There is an urgent need of a prefailure analysis and protection system that can protect the transformers from any kind of liabilities. Analysis of the transformer's dielectric oil is the classical and reliable method used for checking the irregularities present in the transformers by using the Dissolve Gas-in-oil Analysis (DGA) method. Several gases are generated during the normal operation of a transformer. The ratio and concentration of certain gases facilitate the operator in the detection and prediction of the indiscretion and problems that exists in the transformers. The main gases responsible for the faults are methane (CH_4), acetylene (C_2H_2), ethane (C_2H_6), and ethylene (C_2H_4) [13]. Problems like corona discharge, overheating, and arcing in the transformers are easily detected by DGA.

There are several methods available to analyze the faults, such as the (i) International Electro technical Commission (IEC) ratio method, (ii) Rogers ratio method, (iii) Doernenburg method, (iv) Duval triangle method, and the Key gas method. The first three methods do not give any sort of quantitative indication of the fault. In many cases, where multiple faults occur, gases produced from different types of faults are mixed up, creating confusing ratios among the various components of the gases. For our analysis, we will follow the IEEE standard C57.104, based on the Total Dissolve Concentration of Gases (TDCG) and the Key gas method. It measures the concentration of each fault gas produced in the transformer

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http://dx.doi.org/10.1016/j.ijepes.2014.12.005
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during a fault. In this method, the individual concentration of each gas is measured rather than the ratio which is the basic principle of this method. The use of DGA in the transformer is widely accepted for analyzing and spotting the faults as it can diagnose the degradation of the transformer and can estimate its life efficiency [16]. In addition, it can appraise the internal situation of the transformer and plays a crucial part of the maintenance checking and testing system.

Soft computing is a consortium of methodologies that works synergistically and provides, in one form or another, flexible information processing capability for handling real-life ambiguous situations. It aims to exploit the tolerance for imprecision, uncertainty, approximate reasoning, and partial truth in order to achieve tractability, robustness, and low-cost solutions. The guiding principle is to devise methods of computation that leads to an acceptable solution. Several methods have been devised for using Artificial Intelligence (AI) and Soft Computing (SC) for more advanced and accurate diagnosis of transformers [4,17]. In 2012, Souahlia et al. used fuzzy logic, Support Vector Machine (SVM) and Neural Networks (NN) for fault diagnosis in the transformers [18]. Way back in 1997, Huang et al. showed the use of fuzzy logic for diagnosing the faults in the transformer [22]. A set of induced rules was generated from a quantitative data using a fuzzy set based learning algorithm [15]. But the membership function used in fuzzy is not suitable for representing the boundary value conditions [5,6]. In 2005 Ganyun et al. used SVM for identifying the faults in the transformers [19]. It provides a three layered classifier for classifying the state of the transformer. Although it showed a good reliability and is suitable for online fault diagnosis, but the selection of the exact kernel function and the optimization of parameters to make a SVM classifier is a typical problem. The main problem with all these methods is that they are mostly suitable for a transformer having a single fault or any dominating fault. There is no application focusing on the prediction of faults and real trend analysis.

There are several problems associated with an electrical transformer, such as, overloading, overvoltage, overheating and other factors that ultimately lead to a permanent failure. As such, there is a major need of monitoring the parameters associated with the transformer to prevent it from shutting down. Therefore, there is an acute need of new technologies which can monitor the supply systems more effectively to prevent them from unexpected and unconditional failures. *Soft Computing* (SC) hybridization is an association of computing methodologies centering on *Fuzzy Logic* (FL), *Neural Computing* (NC), *Genetic Computing* (GC), *Probabilistic computing* (PC) and their hybridization [1–3]. Collectively, these methodologies provide a foundation for the conception, design and deployment of the intelligent systems. The basic idea underlying SC is that its constituent methodologies are, for the most part, complementary rather than competitive. The complementarity of the constituents of soft computing implies that their effectiveness may be enhanced by using them in combination rather than isolation. At this juncture, the most visible systems of this combined type are the neuro-fuzzy systems. Less visible, but potentially of equal importance are the fuzzy-genetic systems. Each of the constituents of soft computing has a set of capabilities to offer. In the case of fuzzy logic, it is the machinery for dealing with imprecision, information granulation and computing with words. For this purpose, the principal tools are provided by the fuzzy logic center on the use of linguistic variables and the calculation of fuzzy based "*if-then*" rules. In the case of genetic computing, the principal tool is a systematized random search. The most known methods of hybridization of these tools are (i) Neural-Fuzzy Computing, (ii) Fuzzy Genetic Computing, (iii) Genetic-Neural Computing (iv) and Neuro-Genetic-Fuzzy Computing.

In this work, we have used Genetic-Neural Computing using DGA analysis, where the challenge is to build a practical neural network choosing the right architecture and the right learning parameters to find the faults present in the transformers [13]. We know that the Multilayer Perceptron (MLP) with one hidden layer, using the sigmoid transfer function, could perform any mapping from a set of inputs to the desired outputs. Unfortunately, this tells us nothing about the learning parameters, the necessary number of neurons, or whether any additional layers would be beneficial. It is, however, possible to use a genetic algorithm to optimize the network design. A suitable cost function might combine the root mean square error with the duration of training [2]. Supervised training of a neural network involves adjusting its weights until the output patterns are obtained for a range of input patterns. They must be as close as possible to the desired patterns. The different network topologies use different training algorithms for achieving this weight adjustment, typically through back-propagation or errors. However, it is also possible to use GA for training the network. This can be achieved by allowing each gene to represent a network weight so that a complete set of network weights is mapped onto an individual chromosome. Each chromosome can be evaluated by testing a neural network with the corresponding weights against a series of test patterns. A fitness value can be assigned according to the error so that the weights represented by the fittest generated individual corresponds to a trained neural network [3–5]. The most crucial part of using neural network in our system lies in the fact that it can learn and update its knowledge whenever it is required [8,9]. It offers a far superior performance than the other systems due to the non-linear mapping property of the neurons. Following this model, the operator will be able to conduct prefailure analysis and plan for the required maintenance checks.

The rest of the paper is structured as follows: Section 'Cause of gas formation' presents the cause of gas formation. Section 'Need of a hybrid system' presents the main tools used in the hybrid system, while in Section 'Main stages of the suggested hybrid system', the suggested hybrid system that contains various stages are explained. Section 'Experiment' shows the experiments. Finally, the conclusion of the paper is presented in Section 'Conclusion'.

Cause of gas formation

The main and the most profound cause of gas formation in the transformer is thermal heating and electrical discharges. It decomposes the oil into different gases like CO, CO_2, C_2H_2, C_2H_4, C_2H_6, H_2, and CH_4. The cellulose and the minerals present in the transformer oil decompose to produce these gases as shown in Fig. 1. The decomposition of cellulose produces carbon oxides, methane and some hydrogen. The rate of production of these gases abruptly increases with the increase in temperature and volume of the material present in the oil.

Beta fluid and mineral oil consist of a variety of hydrocarbon molecules. They decompose into active hydrogen atoms and

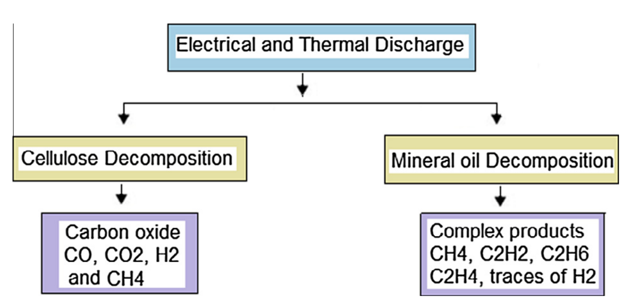

Fig. 1. Composition of the gases evolved during a normal functioning of a transformer.

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