UNIVERSITI PUTRA MALAYSIA

TRANSFORMER HEALTH INDEX ASSESSMENT BASED ON NEURALFUZZY METHOD UTILISING MONTE CARLO SIMULATION

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TRANSFORMER HEALTH INDEX ASSESSMENT BASED ON NEURAL-FUZZY METHOD UTILISING MONTE CARLO SIMULATION

By

EMRAN JAWAD KADIM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements of the Degree of Master of Science

September 2016

This work is dedicated to…..

My family…

My country…

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

TRANSFORMER HEALTH INDEX ASSESSMENT BASED ON NEURAL-FUZZY METHOD UTILISING MONTE CARLO SIMULATION

By

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September 2016

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Transformers can be subjected to multiple types of stresses which could reduce their reliability under long service period. Since transformers are one of the important equipment in power systems, it is important to monitor its condition in order to avoid unnecessary failures and this can be done through a condition based management. Normally, the condition of transformers is evaluated through a single quantitative indicator known as Health Index (HI). Conventionally, HI is determined by scoring method that based on historical information of transformers population and expert judgement. Alternatively, Artificial Intelligence (AI) techniques like Fuzzy Logic (FL) and Artificial Neural Network (ANN) were proposed to overcome these drawbacks. However, these techniques suffer from complexity of producing the inference rules of FL and difficulty of choosing the appropriate ratio of training data for ANN.

In this research, the aim is to apply an alternative method to determine the HI of transformers based on Neural-Fuzzy network (NF) method that can overcome the issues in previous AI and scoring methods. Two schemes were implemented to train the NF network which were based on in-service condition data and Monte Carlo Simulation (MCS) data. The conventional scoring method was also applied for comparison purpose. The performances of these methods were tested on two case studies which had transformers with voltage level less than 69 kV. In-service condition data such as furans, dissolved gases, moisture, AC Breakdown Voltage (ACBDV), dissipation factor (DF), acidity, interfacial tension (IFT), colour and age were fed as input parameters to the NF network. Multiple studies were carried out to test the performance of NF on HI of transformers which included the effects of training data number, age, dissolved gases and in-service condition data.

It is found that the ratio of 80% training and 20% testing is sufficient for NF trained by in-service condition data method. For NF trained by MCS data method, the optimum number of training data required is 1000. The introduction of age in the NF method provides additional input for assessment of transformers. The NF trained by

MCS data has no issue adapting with Total Dissolved Combustible Gases (TDCG) as input data. However, NF method requires a minimum number of in-service condition input data in order to carry out practical assessment on transformers condition. In general, compared to the other two methods, NF trained by MCS data method can provide a realistic alternative assessment of transformers. This technique can be used to diagnose the condition of transformers without the reliance on the historical information of transformers population and expert judgment.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

PENILAIAN INDEKS KESIHATAN ALAT UBAH BERDASARKAN KAEDAH NEURAL-FUZZY MENGGUNAKAN SIMULASI MONTE CARLO

Oleh

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Pengubah boleh tertakluk kepada pelbagai jenis tekanan yang boleh mengurangkan kebolehharapannya di bawah tempoh perkhidmatan yang panjang. Memandangkan pengubah adalah salah satu peralatan yang penting di dalam sistem kuasa, adalah penting untuk memantau kesihatan pengubah untuk mengelakkan kegagalan yang tidak perlu dan ini boleh dilakukan melalui pengurusan berdasarkan keadaan. Kebiasaannya, keadaan pengubah dinilai melalui penunjuk kuantitatif tunggal yang dikenali sebagai Indeks Kesihatan (HI). Secara lazimnya, HI ditentukan dengan kaedah pemarkahan yang berdasarkan maklumat sejarah pengubah penduduk dan pertimbangan pakar. Sebagai alternatif, teknik Kepintaran Buatan (AI) seperti Logik Fuzzy (FL) dan Rangkaian Neural Buatan (ANN) telah dicadangkan untuk mengatasi kelemahan ini. Walau bagaimanapun, teknik ini mempunyai kerumitan untuk menghasilkan peraturan penaakulan untuk FL dan kesukaran memilih nisbah data latihan yang sesuai untuk ANN.

Di dalam kajian ini, tujuannya adalah untuk mengaplikasikan satu kaedah alternatif untuk menentukan HI pengubah berdasarkan kaedah rangkaian Neural-Fuzzy (NF) yang boleh mengatasi isu-isu dalam kaedah-kaedah AI yang lepas dan pemarkahan. Dua skim telah dilaksanakan untuk melatih rangkaian NF yang berdasarkan data keadaan dalam perkhidmatan dan data Simulasi Monte Carlo (MCS). Kaedah konvensional pemarkahan juga digunakan untuk tujuan perbandingan. Prestasi kaedah-kaedah ini telah diuji ke atas dua kajian kes yang mempunyai pengubah dengan tahap voltan kurang daripada 69 kV. Data keadaan dalam perkhidmatan seperti furans, gas terlarut, lembapan, AC Voltan Pecah Tebat (ACBDV), Faktor Lesapan (DF), keasidan, Tegangan Antara Muka (IFT), warna dan umur telah dijadikan sebagai parameter masukan kepada rangkaian NF. Pelbagau kajian telah dijalankan untuk menguji prestasi NF kepada HI pengubah termasuk kesan bilangan data latihan, umur, gas terlarut dan data keadaan dalam perkhidmatan.

Ianya didapati bahawa nisbah data latihan 80% dan ujian 20% adalah mencukupi untuk kaedah NF yang dilatih dengan data keadaan dalam perkhidmatan. Untuk kaedah NF yang dilatih dengan data MCS, jumlah optimum data latihan yang diperlukan adalah 1000. Pengenalan umur dalam kaedah NF memberi tambahan masukan untuk penilaian pengubah. NF yang dilatih dengan data MCS tidak mempunyai isu menyesuaikan diri dengan Jumlah Gas Terlarut Boleh Bakar (TDCG) sebagai data masukan. Walau bagaimanapun, kaedah NF memerlukan bilangan minimum masukan bagi data keadaan dalam perkhidmatan untuk membuat penilaian praktikal kepada keadaan pengubah. Secara umumnya, berbanding dengan dua kaedah lain, kaedah NF yang dilatih dengan data MCS boleh memberikan penilaian alternatif yang realistik kepada pengubah. Teknik ini boleh digunakan untuk mendiagnosis keadaan pengubah tanpa pergantungan kepada maklumat sejarah pengubah penduduk dan pertimbangan pakar.

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I certify that a Thesis Examination Committee has met on 20 September 2016 to conduct the final examination of Emran Jawad Kadim on his thesis entitled "Transformer Health Index Assessment Based on Neural-Fuzzy Method Utilising Monte Carlo Simulation" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

AI	Artificial Intelligent
ANN	Artificial Neural Network
ACBDV	AC Breakdown Voltage
CBM	Condition-Based Management
CIGRE	Conference Internationale des Grandes Reseaux Electriques
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CH_4	Methane
C_2H_6	Ethane
C_2H_4	Ethylene
C_2H_2	Acetylene
DGA	Dissolved Gas Analysis
DGAF	Dissolved Gas Analysis Factor
DF	Dissipation Factor
FF	Furan Factor
FFANN	Feed Forward Artificial Neural Network
FL	Fuzzy Logic
FIS	Fuzzy Inference System
FSVM	Fuzzy Support Vector Machine
HI	Health Index
H_2	Hydrogen
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFT	Interfacial Tension
MCS	Monte Carlo Simulation
MF	Membership Function
NF	Neural-Fuzzy
OQF	Oil Quality Factor
ppm	part per million
TBM	Time-Based Management
TDCG	Total Dissolved Combustible Gases

CHAPTER 1

INTRODUCTION

1.1 Introduction

Transformers are among the key components in the power system network and their main function is to ensure reliable delivery of electricity supply from generating plants to consumers. Generally, transformers are well-designed with sufficient safety margin to withstand normal system events in the power system networks. However, while transformers experiencing ageing, the capability to withstand these events could be reduced as a result of degradation of insulation materials [1]. Without proper assessment and intervention, transformers could fail and this failure can lead to huge losses to the utilities and consumers [2].

Ageing of transformers is a complex process which involves multiple mechanisms. There are two main materials in transformers that can be subjected to ageing which are oil and paper. The ageing of these materials could be accelerated by the presence of heat, moisture, oxygen and acidity [3]. Under normal ageing, the by-products generated by the ageing process of oil and paper include moisture, acidity, furans and dissolved gases [4]. The concentrations of these by-products will slowly increase under normal ageing; however, under extreme condition, a significant increase will occur. For example, under local overheating of insulation paper, the concentration of furans could significantly increase [5]. In a similar case, under arcing event, the concentration of the acetylene will be high [6]. Therefore, assessment of transformers condition should not only cater for the normal events but also consider the extreme events. Through this approach, the sudden failure event can be avoided and the utilization of the transformers can be maximized.

Nowadays, utilities have migrated from the conventional Time-Based Management (TBM) to Condition-Based Management (CBM) in order to optimize the investment that had been initially carried out [7]. With the current economic scenarios, CBM becomes increasingly important, especially to avoid unnecessary losses. The numbers of measurement for condition assessment of transformers have increased in order to ensure that every aspects of the asset health are covered. However, assessing the health of transformers through individual measurements is quite complex. Therefore, an assessment technique known as Health Index (HI) has been introduced which relies on a single indicator to assess the overall condition of transformers [8].

HI consists of multiple transformers condition data assessment that is computed based on set of algorithms [9]. Coupled with the historical information of transformers and probability failure assessment, HI can be used for maintenance scheduling and replacement strategies. Normally, the main components that exist in HI are the quality of the oil, health of the paper, loading history and condition of the winding and tank [10]. There are multiple measurements that are obtained for assessment of the quality of the oil such as AC Breakdown Voltage (ACBDV), dielectric properties, acidity, moisture, colour and interfacial tension (IFT) [11]. The degradation state of the paper can be determined based on furans measurement [12]. Since the HI could also be used to evaluate the abnormal system events, information from measurements such as dissolved gases in oil, frequency response, partial discharge and recovery voltage measurements are also considered in the computation [1]. Apart from oil and paper condition, the information on the loading history is equally important in the determination of HI of transformers [8]. The information on the winding and tank condition are also considered in the HI computation through measurements such as frequency response analysis, turn ratio and resistance measurements as well as visual observations of the tank [13].

The conventional computation of HI is known as the scoring method which is normally unique for each utility depending on the requirement and the historical transformers population data. The scoring method relies on the ranking analysis and each parameter is given a distinctive weighting factor depending on its significance which is based on either expert judgment or utility requirement. In recent years, Artificial Intelligence (AI) has been introduced as an alternative approach for condition assessment of transformers. AI can help to overcome the previous issues in the existing scoring method approach such as high dependency on expert judgment [14]. A number of studies were carried out previously to adopt AI for obtaining transformers HI. Several AI methods had been used to determine the HI of transformers such as Fuzzy Logic (FL) [14], Artificial Neural Network (ANN) [15], Orthogonal Wavelet Network [16] and Fuzzy Support Vector Machine (FSVM) [17]. Currently, there have been very few studies conducted on applying Neural Fuzzy (NF) to determine HI of transformers. This technique was applied in other transformers studies which include the faults detection based on dissolved gases in oil [18-20].

1.2 Problem statement

Most of the utilities nowadays are using scoring method to determine the HI of transformers. It is based on scoring system of which the in-service transformers condition data is ranked according to the range provided in IEEE C57.106-2006 [21], IEEE C57.104-2008 [22], IEC 60422 [23] and IEC 60599 [24]. In addition, a specific weighting factor is allocated to each of the condition data before the final HI is computed. There are, however, several issues with the existing HI method that could cause difficulty on the assessment of transformer condition as follow:

- One of the issues is that scoring method is specific for each utility. The same algorithm of scoring method used for one utility may not possibly be suitable for application in another utility. One of the main reasons is due to difference in the scoring ranking and weighting factors used in the algorithm.
- The weighting factors are usually unique and depend heavily on the previous assessment of the historical transformers population data and

transformers expert judgment. Therefore, there could be a discrepancy for different utilities for determination of HI.

- This leads to difficulty in finding the suitable algorithm suited for specific transformers condition data obtained from utility. Furthermore, if there are no enough historical transformers population data coupled with the misjudgement of the transformers expert, the algorithm could provide unreliable HI.
- There are several AI methods that have been implemented as alternatives to determining HI of transformers. The implementation of these methods, however, has several issues such as the complexity of producing the inference rules and choosing the appropriate ratio of training data to cover the testing ranges.

1.3 Objectives of Study

The aim of this research is to apply an alternative method to determine the HI of transformers based on NF method. In order to achieve the aim of this research, several objectives have been identified as follows:

1- To evaluate HI of transformers through scoring method based on the available in-service condition data.
2- To determine HI of transformers through the NF method based on in-service condition data only.
3- To assess HI of transformers through the NF method based on Monte Carlo Simulation (MCS) data.

1.4 Scope of Study

The scope and limitations of this research are as follows:

1- The scope of this research is based on commonly available data obtained from utilities which are furans, dissolved gases, moisture, ACBDV, dissipation factor, acidity, interfacial tension, colour, and age.
2- For scoring method, the calculation of HI is carried out on transformers only where the tap changer is omitted.
3- The transformers data in the case study obtained from utilities and literature have voltage level less than 69 kV.

1.5 Contribution of study

The major contributions of this study are detailed as follow:

- The application of NF method for the determination of the HI of transformers which is based on the computation technique. It does not rely on the historical transformers population information and experience from transformers experts. In addition, the application of MCS in the NF method is a unique approach to overcome the over reliance on the transformers in-service condition data to optimize the network. This approach provides a generic model that can be used for assessing the HI of transformers from different utilities.

- The introduction of age in the computation of NF method is carried out to avoid misinterpretation of HI of transformers. This would help the utilities to properly manage and plan their maintenance and replacement strategies which in turn will optimize their investment.

1.6 Thesis layout

Thesis structure of this work displays a number of stages which together form a basis to achieve the research aims. The thesis structure consists of five chapters as detailed below:

In Chapter 1, a concise and comprehensive introduction of the research is presented along with the problem statement, research objectives, and the scope of the study.

In Chapter 2, a detailed related literature review of previous studies to research topic is described. This chapter contains a general overview of transformers HI, the scoring method and highlights of the gap of other works that used different AI techniques to evaluate the HI of transformers.

In Chapter 3, a description of research methodology is presented. The methodology includes the flow of the research, a discussion on how AI techniques will be used, the data collection and the rest of modifications that were done for NF network.

In Chapter 4, the results of testing NF network with different data are reported. A discussion for each method limitations based on the findings that are obtained from different studies is presented. Furthermore, this chapter presents a comparison between the proposed and scoring HI methods is established.

Finally, Chapter 5 presents a brief summary of this research work, highlights the most significant findings and improvements of the research, and offers recommendations for the possible future works.

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