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MODIFICATION OF WEIGHT VALUE IDENTIFICATION IN TRANSFORMER HEALTH INDEX ASSESSMENT MODEL

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By

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Transformer is one of the most important components in the power system. Fault that occurs in transformer may result in power supply interruption which will also cause environmental damage, revenue losses and disruption in end users activities. Utility companies have adopting transformer asset management (TAM) with the aid of transformer health index (THI) to examine the health condition of the transformer. Over the years, the weight value for components and parameters in THI assessment model are determined by subjective judgment of transformers' expert. Presently, general research on mathematical weight value identification is still very much in its infancy. Therefore, a substantial study on weight value identification by proper mathematical approach is essential in order to justify the use of THI assessment model for assessing health condition of transformers. Seven previous THI assessment models, which depending on subjective judgment of transformer's expert were reviewed and named as THI Assessment Models 1 to 7. However, due to assumptions used and unknown references on certain parameters of THI Assessment Models 3 to 7, only THI Assessment Models 1 and 2 were used as references to be compared to the two proposed assessment models, named as THI Assessment Models A and B. It is demonstrated that THI determination in the proposed THI Assessments Model A and B are easier to be implemented compared to THI Assessment Models 1 and 2. This is due to the reason that direct mathematical steps are employed in the proposed THI Assessment Models A and B, whereas THI Assessment Models 1 and 2 are solely based on experts' judgment and prediction. Therefore, the proposed models are more reliable and do not have to deal with arguments from different experts.

The parameters chosen in this study are Dissolved Gas Analysis (DGA) and Oil Quality Analysis (OQA) where basic equation of THI was used in the model. In the proposed THI Assessment Models A and B, the score value used was in between '0' to '100' and the weight values for components and parameters were determined using Entropy Weight Method (EWM). The calculations of the proposed THI Assessment Models A and B were compared to the THI Assessment Models 1 and 2 using three data populations, where Data Population 1 involve 30 transformers, Data Population 2 involve five transformer and Data Population 3 involve 73 transformers. The results revealed that THI values and transformer condition in THI Assessments Models A and B are in good agreement with THI Assessment Model 2 and contradicted to the THI Assessment Model 1. However, the relationship between THI values with age for THI Assessment Models A and B agree relatively well with both THI Assessment Models 1 and 2. Furthermore, there is strong linear correlation between THI Assessment Models A and B with THI Assessment Models 1 and 2. The results of this study clearly support that the new proposed THI assessment models are more reliable to be used to obtain THI value, compared to the existing THI assessment models which solely depending on the judgment of transformers' expert.

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

PENGUBAHSUAIAN DALAM MENENTUKAN NILAI BERAT DALAM MODEL PENILAIAN INDEKS KESIHATAN PENGUBAH

Oleh

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Pengubah adalah salah satu komponen yang paling penting dalam sistem kuasa. Kegagalan yang berlaku di dalam pengubah boleh menyebabkan gangguan bekalan kuasa yang akan memberikan kesan buruk terhadap alam sekitar, kerugian pendapatan dan menyebabkan aktiviti pengguna tergendala. Syarikat utiliti telah mengguna pakai pengurusan aset pengubah (TAM) dengan bantuan indeks kesihatan pengubah (THI) untuk menilai tahap kesihatan pengubah. Sejak dahulu, nilai berat untuk komponen dan parameter dalam model penilaian THI ditentukan melalui penilaian subjektif oleh pakar pengubah. Pada masa ini, penyelidikan am dalam penentuan nilai berat melalui kaedah matematik masih di peringkat awal. Oleh itu, kajian tambahan dalam penentuan nilai berat menggunakan kaedah matematik adalah penting untuk membuktikan/menyokong penggunaan model penilaian THI dalam menilai keadaan kesihatan sesuatu pengubah. Tujuh model penilaian THI terdahulu yang bergantung kepada penilaian subjektif pakar pengubah telah disemak semula dan dinamakan sebagai Model Penilaian THI 1 hingga 7. Walaubagaimanapun, terdapat banyak andaian dan rujukan-rujukan yang tidak diketahui bagi parameter tertentu dalam Model Penilaian THI 3 hingga 7, maka hanya Model Penilaian THI 1 dan 2 digunakan sebagai rujukan untuk dibandingkan dengan model penilaian THI yang dicadangkan yang dinamakan sebagai Model Penilaian THI A dan B. Penentuan nilai THI dalam Model Penilaian THI A dan B menunjukkan ia adalah lebih mudah untuk digunakan jika dibandingkan dengan Model Penilaian THI 1 dan 2. Ini adalah disebabkan oleh kaedah matematik secara langsung yang digunakan dalam Model Penilaian THI A dan B, manakala Model Penilaian THI 1 dan 2 bergantung sepenuhnya terhadap penilaian subjektif dan andaian oleh pakar. Oleh itu, model penilaian THI yang dicadangkan adalah lebih dipercayai dan tidak bergantung kepada percanggahan pendapat antara pakar.

Parameter yang dipilih dalam kajian ini adalah Analisis Gas Terlarut (DGA) dan Analisis Kualiti Minyak (OQA), di mana formula asas THI digunakan dalam model ini. Dalam model penilaian THI yang dicadangkan iaitu Model Penilaian A dan B, nilai skor yang digunakan adalah antara ‘0’ hingga ‘100’ dan nilai berat bagi komponen dan parameter ditentukan menggunakan Kaedah Berat Entropi (EWM). Pengiraan Model Penilaian THI

A dan B dibandingkan dengan Model Penilaian THI 1 dan 2 dengan menggunakan tiga kelompok data, di mana, Kelompok Data 1 terdiri daripada 30 pengubah, Kelompok Data 2 terdiri daripada lima pengubah dan Kelompok Data 3 terdiri daripada 73 pengubah. Hasil kajian menunjukkan nilai THI dan keadaan pengubah dalam Model Penilaian THI A dan B adalah sama dengan Model Penilaian THI 2 berbanding dengan Model Penilaian THI 1. Walaubagaimanapun, perhubungan antara nilai THI dengan umur dalam Model Penilaian THI A dan B adalah sama dengan Model Penilaian THI 1 dan 2. Tambahan lagi, terdapat hubungan linear yang kuat antara Model Penilaian THI A dan B dengan Model Penilaian THI 1 dan 2. Kesimpulannya, hasil kajian ini menunjukkan bahawa model penilaian THI yang dicadangkan boleh dipercayai untuk digunakan dalam menentukan nilai THI, jika dibandingkan dengan model penilaian THI yang sedia ada di mana model-model ini bergantung sepenuhnya terhadap penilaian subjektif oleh pakar pengubah.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASTM	American Standard Test Method
BDV	Breakdown voltage
CA	Condition assessment
C_2H_2	Acetylene
C_2H_4	Ethylene
C_2H_6	Ethane
CH_4	Methane
CI	Confidence interval
CM	Condition monitoring
CO	Carbon monoxide
CO_2	Carbon dioxide
DF	Dissipation factor
DGA	Dissolved gas analysis
DGAF	Dissolved gas analysis factor
DP	Degree of polymerization
EWM	Entropy weight method
EWHI	Entropy weight health index
FDS	Frequency domain spectroscopy
FFA	Furfural analysis
FRA	Frequency response analysis
H_2	Hydrogen
HI	Health index
HIF	Health index factor
HPLC	High performance liquid chromatography
IEC	International Electro-technical Commission
IEEE	Institute of Electrical and Electronics Engineers
IS	International Standard
KOH	Potassium
LTC	Load tap changer
mg	milligram
N_2	Nitrogen
NN	Neutralization number
O_2	Oxygen
OQA	Oil quality analysis
OQF	Oil quality factor
PD	Partial discharge
PF	Power factor
PI	Prediction interval
ppm	Part per million
RVM	Recovery voltage measurement
SFRA	Sweep frequency response analysis
TAM	Transformer asset management
THI	Transformer health index
TNBR	TNB Research
Tx	Transformer
WC	Water content

LIST OF SYMBOLS

B	Aging coefficient
f	Fault correction factor
f_E	Environmental factor
f_L	Load factor
$HI_{C,H}$	Index based on DGA
$HI_{C,O}$	Health index formed by the carbon-oxygen gas content
HI_{fur}	Health index formed by the furfural content
HI_{iso}	Insulating paper health index
HI_m	Main health index
HI_{oil}	Index based on oil quality factor
P	Judge-matrix
r	Correlation coefficient
R^2	Coefficient of determination
U	Unitary judge-matrix
V	Voltage

CHAPTER 1

INTRODUCTION

1.1 Background

Transformers make up a large part in asset cost structure installed in high-voltage substations. They act as the ‘back-bone’ of a power system as they link the power chain of generation, transmission and distribution substations altogether. Transformers are essential in the transmission of alternating current and are the most costly equipment in the substation [1-3]. Transformers operation may be subjected to operation stresses which are thermal, mechanical, and electrical stresses. These stresses can eventually deteriorate the life of transformer and cause failure to the transformer [4]. Failure occurs when the withstand strength of the transformer with respect to the key properties of the transformer is exceeds the limit of operational stresses [5].

Inadvertent catastrophic failure of a transformers will impose serious consequences regarding power system reliability, revenue and cost for replacement under emergency and environment impact [6-8]. Transformers failure can also cause severe production damage and significant loss throughout the power grid [9]. Unscheduled power supply outages due to transformers failure will also cause significant commercial and industrial losses as well as inconveniences to household electricity users [9-10]. The restoration cost of in-service transformer failures could increases by up to 75% and loss of revenue by 60% [1].

Due to high restoration cost, it is therefore prudent for utility companies to optimize the life of transformers and to mitigate in-service failures [1]. Knowing previous, current and future conditions of transformers are essential to meet the financial and technical performance demand to maximize return on investment and lowering total cost associated with transformer operations. To achieve the optimal balance among capital investments, asset maintenance cost, and operating performance, there is a need to provide economic and technical justifications for engineering decisions and capital replacement plans [11]. Therefore, utilities are adopting transformer asset management (TAM) which focusing on understanding asset condition and performance and improving asset maintenance. TAM which relies on life and condition assessment study outputs also allows asset manager to decide the next action required to prevent any unplanned malfunctions and breakdowns.

Generally, TAM involves a series of processes to examine, analyze and prioritize assets and the work done on those assets across an organization. TAM techniques have evolved from time to time from manual data collection to intelligent framework techniques. TAM has three main activities which can be classified to condition monitoring (CM) and condition assessment (CA), performing maintenance plans and aging, health, end of life assessments [1, 13]. In condition monitoring, all data from operating observations, field, site and laboratory testing are taken. The taken data will be used to assess the health condition of the transformer by taking into account several aspects that affect the future performance. The normal output of condition assessment can range from a simple normal or abnormal assessment to a sophisticated 'asset health index' which is a ranking or scoring system on a single or multiple scale to allow decisions on future maintenance or replacement prioritized over a fleet of units [13]. The transformer health index (THI) is widely used as an indicator for transformers' health so that future actions can be taken to prevent transformer failure issues.

In order to get the correct decision for maintenance action, condition assessment is very crucial. It needs concise, precise and straight to the point value to reflect the health condition of the transformer. Therefore, THI is a practical tool that combines the result of operating observations, field inspections, site and laboratory testing into an objective and quantitative index [2, 15]. THI consists of input, algorithm/equation and output. Currently, several assessment models studied by the researchers and being adopted by the utility company focus on calculating overall THI value and remaining lifetime, expected failure rate and evaluating the overall condition of transformer [2, 16-30]. In conclusion, THI is a powerful tool for managing transformers, identifying investment needs and prioritizing investments into capital and maintenance program [15, 30, 31]. Besides, adopting THI increased the ability to operate networks, not only optimizing the use of existing equipment but also planning the maintenance actions, repairs, refurbishments, relocation or replacement, in the best way.

1.2 Problem Statement

Unplanned transformer failure is a big issue for utility company and end users. On the utility side, there will be major economic implication as the cost to replace malfunction transformer is very high. Utility company will also have bad reputation due to the problem of supplying continuous power supply to the end user. On the end users side, there are major economic implication due to the interrupted production and services. Daily activities cannot be performed because people are too depending on the electricity. Both utility company and end users will be suffered in the occurrence of unplanned power supply outage.

THI has been used to assess the health condition of the transformer. There are many THI assessment models available in the literature which could be used to calculate THI and most of the equations involved scores and weight values [14-16, 19, 22, 24-27, 32, 33]. Usually the value of score and weight rely on subjective judgment of a transformers' expert as different transformer experts will adjust the value of weight depending on their judgments. This will cause different value of THI even if the same input parameters were considered. Weight value is very important as they influenced the final THI value while several researches on mathematical approach of weight identification is still in its infancy. Therefore, in such situations, a substantial study on weight value identification by proper mathematical approach is essential in order to justify the use of THI assessment model for assessing transformer health condition.

1.3 Research Aim and Objectives

The aim of this research is to determine a condition-based asset management tool that quantifies transformer condition and allows for a recommendation regarding the number of transformers that would likely require replacement within future time horizons. In order to achieve the aim of this research, several objectives have been identified as follows:

i. To evaluate the previous THI assessment models with respect to data requirements, calculation models and the reliability of the output.
ii. To develop new THI assessment model for determining transformer health condition.
iii. To validate the performance of new THI assessment model in terms of THI values, conditions, relationship with age and relationship with previous assessment models.

1.4 Scope and Limitation of Work

The scope and limitations of this research work are:

i. This research considers only on two input parameters which are dissolved gas analysis (DGA) and oil quality analysis (OQA). These two parameters which consist of several components would help in demonstrating the use of Entropy Weight Method (EWM). In addition, dielectric oil is considered as one of the key sources to detect incipient and fast developing faults, insulation trending and generally reflects the health condition of the transformer [34].
ii. This research focuses on the basic mathematical equation of THI.
iii. This research focuses on calculating THI value for transformer with 11/33 kV rating only.
iv. This research evaluates THI for a random period of transformer data in selected populations.

1.5 Thesis Outline

This thesis consists of five chapters, which cover the introduction, literature review, research methodology, results and discussions and finally conclusions, contributions and recommendations for future work.

Chapter 1 describes introduction of this research along with the problem statement, research aim and objectives, scope of work and limitation of the study.

Chapter 2 discusses the formulation of transformer health index, which consists of input parameter, equation and output. Besides that, previous THI assessment models were also discussed in this chapter. The information from previous THI assessment models were used to develop new THI assessment models.

Chapter 3 presents the methodology for previous THI assessment models and the work done to develop new proposed THI assessment models. It describes the score and weight value identification for the proposed THI assessment models. Observations of the results for new and previous THI assessment models are also discussed.

Chapter 4 discusses the final results of the research. The results for previous and proposed THI assessment models are compared and discussed in detail. The THI values, condition, relationship between THI value with age and relationship between all previous and proposed THI assessment models are observed.

Chapter 5 summarizes and concludes this research. At the end of this chapter, contributions and recommendations for future work on THI assessment models are included.

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LIST OF PUBLICATIONS

Journal

[1] **A. Azmi,** J. Jasni, N. Azis, M. Z. A. Kadir, "Evolution of Transformer Health Index in the Form of Mathematical Equation", Renewable and Sustainable Energy Reviews, Vol. 76, pp. 687-700 – published, available online on 27 March 2017

[2] J. Jasni, **A. Azmi**, N. Azis, M. S. Yahaya, M. A. Talib, "Assessment of Transformer Health Index Using Different Model", Pertanika Journal Science & Technology, Vol. 25, pp. 143-150 – published, available online on 19 May 2017

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[1] **Akmalina Azmi**, J. Jasni, N. Azis, "Health Index as a Tool for Transformer Asset Management", International Conference on Power, Energy & Communications Systems (IPECS), UniMAP, Perlis, August 2015

[2] **A. Azmi**, J. Jasni, N. Azis, M. Z. A. Kadir, M. S. Yahaya, M. A. Talib, "Assessment of Transformer Health Index by Using Different Model", International Conference on Electrical and Electronic Technology (ICEETech), UPM, Selangor, August 2016

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[1] **A. Azmi**, J. Jasni, N. Azis, M. A. Talib, "Analysis of Transformer Health Index using Scoring and Ranking Method", 2016 MyHVnet Colloquium, UTM Skudai, Johor, January 2016

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[1] **A. Azmi**, J. Jasni, N. Azis, "An Approach of Transformer Health Index Condition Assessment", The 4th Symposium on Applied Engineering and Sciences 2016 (SAES2016), Kyushu Institute of Technology, Fukuoka, Japan, 17-18 December 2016

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