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Assessment of Transformer Health Index Using Different Model

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ABSTRACT

Transformer failures lead to interruption of power supply. Therefore, asset management is important to monitor the efficient functioning of transformers. An important approach in asset management is condition assessment whereby the health status of the transformer is assessed via a health index. There are many methods in determining the final value of a health index. This paper examines how different assessment methods can be used in order to come up with the final health index and output of final health index. The output trend shapes are almost the same for Assessment Model A, B and C except for Assessment Model D. There is no strong correlation between the health index and age of the transformer. Generally, the value of health index of the transformer is reflected by its operation and loading history .This paper hence examines the assessment steps and results that will guide the development of a new approach to determine health index value.

Keywords: Transformer, asset management, condition assessment, transformer health index

INTRODUCTION

Continuous and steady supply of electricity is crucial to support manufacturing, production, the services industry and daily needs of residents. Power outages affect the environment, disrupt transportation system and will result in heavy losses for businesses particularly in the manufacturing and services sector in addition to bringing disrepute to the utility company leading to the latter's loss of revenue and market backlash. Continuous power supply depends on the condition of the transformer as it is the 'back-bone' of a power system. A transformer is used to step up or step down the voltage from the generator to be supplied to the end user. Thus, asset management is important to examine, analyse

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and prioritise the assets and their maintenance needs of . There are a lot of methods related to asset management such as fuzzy logic, digital signal processing algorithms, principal component analysis (PCA) algorithms and back-propagation artificial neural network (BP-ANN) algorithm (Abiri-Jahromi et al., 2013; Abiri-Jahromi et al., 2013; Abu-Elanien et al., 2011; Abu-Elanien et al., 2012; Abu-Elanien et al., 2010; Arshad, et al., 2014; Brittes et al., 2014; Dominelli, 2004; Ma et al., 2015; Trappey et al., 2015).

There are a few approaches to asset management such as condition assessment of the transformer. In condition assessment, health index is used to examine the condition of the transformer and whether it needs to be maintained, repaired and upgraded, replaced, monitored or have contingency control. Health index is a combination of results from operating observations, field testing and site and laboratory testing. This results will be converted into a quantitative index to show the condition of the transformer. Health index usually consists of input, algorithm and output. Figure 1 shows the basic concept of health index. There are many assessment models available in finding the final value of health index.

In addition to the theory, this paper presents the results of transformer condition assessment using Assessment Model A, B, C and D. These are done in order to examine the steps and the output of the final health index. The input parameters for the calculation are limited to dissolved gas analysis, oil quality analysis and furan analysis. The output of the assessments is compared to each other to assess the trend of the output.

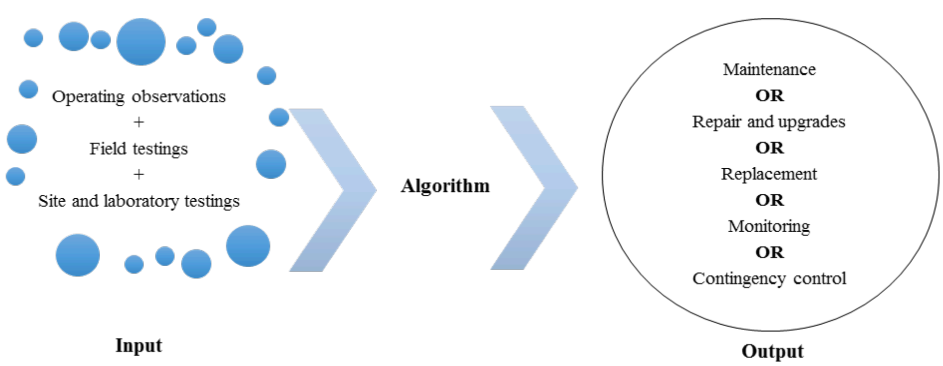

Figure 1. Concept of health index

ASSESSMENT MODEL

Assessment Model A

This model uses scoring and ranking in determining the final health index value for power transformer (Jahromi et al., 2009; Naderian et al., 2008). The input parameters for this model consist of results of operating observations, field inspections and site and laboratory testing. It will be then converted to a quantitative index which will identify the overall condition of a transformer. Some of the inputs are dissolved gas analysis, oil quality, furfural, power factor, tap changer, load history and maintenance data.

The factor for each parameter (F_i) is determined by using scoring and weighting for all component in a parameter (if there are many components in a parameter). The needs for parameter factor determination is to combine all the components into one quantitative index. The scoring (S_i) value is determined by the recommendation limit from IEEE and IEC. Weighting (W_i) factor for the parameter is usually justified by subjective judgment from the experts. The parameter factor is then converted to health index factor (HIF) by using a certain range. The range is divided into five conditions which are good (A=4), acceptable (B=3), need caution (C=2), poor (D=1) and very poor (E=0). Next, the final health index is calculated by using Equation (1). The output of the health index is determined by the value of 100 which means good condition to 0 which means very poor condition. Figure 2 shows the flow for determining the final health index value for a transformer.

$$HI = 60\% \times \frac{\sum_{j=21}^{21} K_j HIF_j}{\sum_{j=1}^{21} 4K_j} + 40\% \frac{\sum_{j=22}^{24} K_j HIF_j}{\sum_{j=22}^{24} 4K_j} \tag{1}$$

K_j = weighting factor for parameter

HIF_j = health index factor

60% = weighting factor assigned to transformer

40% = weighting factor assigned to LTC

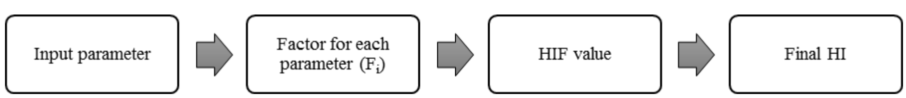

Figure 2. HI value determination

Assessment Model B

In this model, scoring and ranking is used to determine final value of health index (Haema et al., 2012; Haema et al., 2013). The input parameters are divided into three types of tests: electrical tests, insulating oil test and visual inspection. Some parameters are power factors, dissolved gas analysis for both main tank and OLTC compartment, furfural, oil quality for both main tank and OLTC compartment and visual inspection.

The scoring and weighting value is similar to the value from Naderian assessment method. The method for finding the final value of health index is similar to Naderian assessment model. The difference between this method and Naderian assessment method is the equation for factor of each parameter. In this method, the denominator for finding factor (F_i) is maximum score

(S_i) multiplied with weighting (W_i). The equation factor (F_i) is then multiplied by 100. Final health index value is calculated using Equation (2).

$$(\%)HI = \left(0.6\frac{\sum_{j=1}^{j=17}(K_j \times HIF_j)}{\sum_{j=1}^{j=17}(HIF_{max} \times K_j)} + 0.4\frac{\sum_{j=18}^{j=21}(K_j \times HIF_j)}{\sum_{j=18}^{j=21}(4 \times K_j)}\right) \quad (2)$$

K_j = weighting factor for parameter

HIF_j = health index factor

0.6 = weighting factor assigned to transformer

0.4 = weighting factor assigned to LTC

Assessment Model C

This model has three tiers (Ghazali et al., 2008, Ghazali et al., 2009). Tier 1 is the baseline audit for the transformer fleet to assess the presence of fault, quality of insulation oil, insulating paper degradation level, physical, thermal and operating performance. Tier 2 is applied if the result of Tier 1 is abnormal or below 55. Tier 3 is applied if the result of Tier 2 is abnormal or below 55. The input parameters involved for Tier 1 are dissolved gas analysis, oil quality analysis, furfural analysis, inspection on physical conditions and operating performance and thermography. For Tier 2, transformer turns-ratio measurement, winding resistance measurement, dielectric dissipation factor/tan delta measurement, excitation current measurement, insulation resistance and polarisation index (PI). For Tier 3, frequency response analysis (FRA) and partial discharge measurement (PD).

The scoring of the condition of a parameter is determined by referring to IEEE, IEC, and Bureau of Reclamation (*Facilities Instructions, Standards and Techniques: Transformer Diagnostics (FIST 3-31)*, 2003). The score of the parameter is ranked from 3 to 0. Next, the value of rank is converted to a fix amplified ranking number value which are 3 for 20, 2 for 12, 1 for -18 and 0 for -20. The total ranking score is calculated by multiplying amplified ranking number and weighting factor. To obtain final Tier 1 transformer condition index (TCI), percentage estimated life used above 100% is subtracted from the sum of individual total ranking score (A). The similar step of calculating final value Tier 1 is applied to obtain the final value of TCI for Tier 2 and Tier 3. Output ranked from 100 (good) to <10 (very poor).

Assessment Model D

This model also has two tiers for assessing the condition of a transformer (Malik et al., 2012). Tier 1 shows the transformer condition assessment summary and Tier 2 indicates the transformer condition summary. The input parameters for Tier 1 are insulating oil analysis (DGA & furan), power factor and excitation current tests, operation and maintenance history, mechanical parts (bushing, tank, cooling). The input parameters for Tier 2 are turn ratio and sweep frequency response analysis (SFRA).

The score and weighting factor for each parameter in Tier 1 are determined by referring to the standard set by Bureau of Reclamation. Total score for each indicator is obtained by multiplying the score and weighting factor. Sum of the individual indicator is named transformer condition index. Net transformer is defined by Tier 1 transformer condition index minus Tier 2 adjustment. Output ranked from 0 (poor) to 10 (good).

ASSESSMENT RESULT AND DISCUSSION

Four transformer condition assessment models have been performed on 73 units of transformer. The age of the transformers is between 1 and 30 years. The input parameter is limited to dissolved gas analysis, oil quality analysis and furan analysis. The output value of health index for Assessment Model A, B and C assessment model are between 0 and 100 with 0 denoting 'very poor' condition and 100 denoting 'very good' condition of a transformer. For Assessment Model D, the value range of health index is from 0 to 10; 0 indicates 'poor' condition and 10 indicates 'good' condition of a transformer. Figure 3(a), 3(b), 3(c), and 3(d) indicate the average condition of the fleet to age. Units which are above the regression line are in better

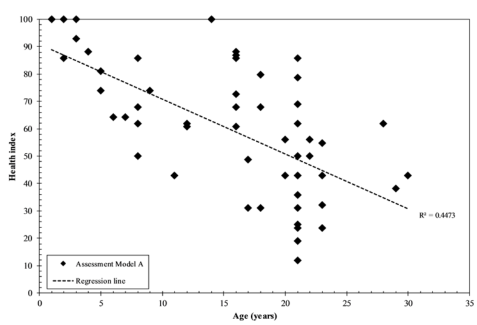

Figure 3(a). Health index as a function of age and linear relation for Assessment Model A

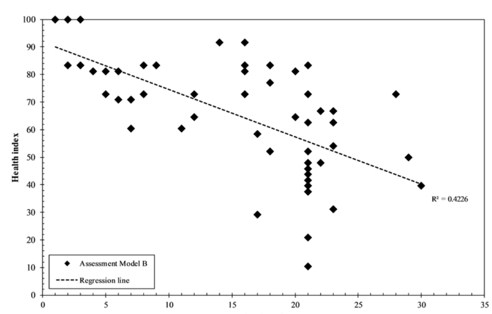

Figure 3(b). Health index as a function of age and linear relation for Assessment Model B

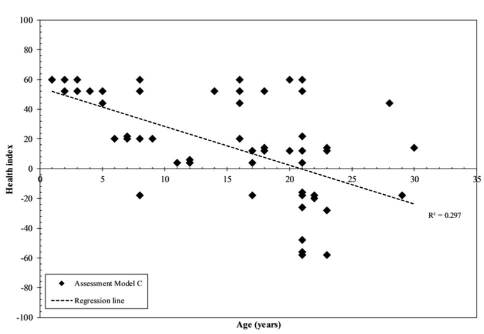

Figure 3(c). Health index as a function of age and linear relation for Assessment Model C

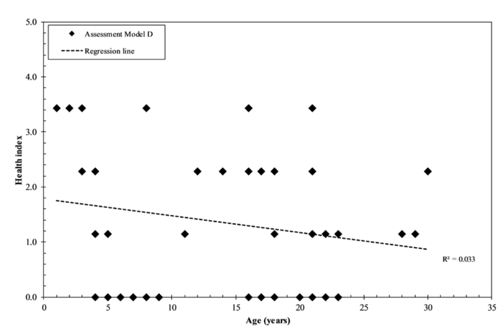

Figure 3(d). Health index as a function of age and linear relation for Assessment Model D condition compared with the units below the regression line. This is because most of the values of health index on the upper side of regression line show 'fair' to 'very good' condition of the transformer. The same value of health index for different ages of transformers is usually because their health condition depends on the operation or loading history for a transformer. For Assessment Model D, the value of health index shows poor condition due to the limited data for calculation as the input for Tier 1 are oil analysis, power factor and excitation current test, operation and maintenance history and age.

Value of coefficient of determination, r^2 is a measure of how well the regression line represents the plotted data. Figure 4 shows the comparison of regression line obtained from four transformer assessment models. From the analysis, the range of r^2 is from 0.03299 to 0.44727. Assessment Model A shows the highest value of r^2 among all models. Assessment Model D shows the lowest value of r^2. This value shows poor correlation between the value of health index to the age of the transformer. Figure 5 presents the trend shape comparison of all models. It can be seen that Assessment Models A, B and C show almost the same trends compared with Assessment Model D. The different value of the output is because of the different value of scoring and weighting used for calculating the final value of health index. The value of health index for Assessment Model C portrayed a negative value because of the amplified ranking number used in the calculation. This condition also shows that the units which are below 55 need to perform Tier 2 and if the condition shows an abnormal result, Tier 3 will be performed. The output shape of Assessment Model D is different because there is limited data for Tier 1 and Tier 2.

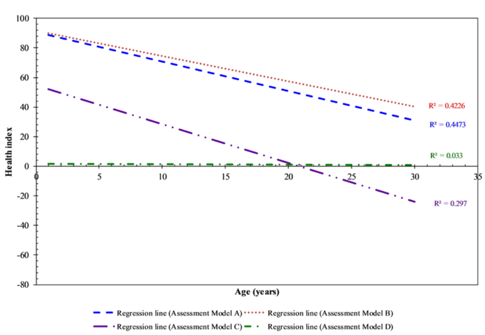

Figure 4. Regression line for all assessment models

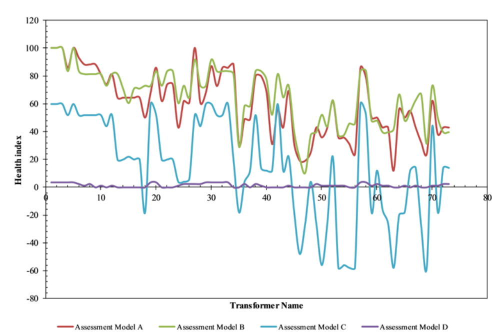

Figure 5. Waveshape for all assessment models

CONCLUSION

Evaluation of transformer health index using Assessment A, B, C and D have been presented in this paper. This study examined the methods to obtain transformer health index and trend of final output of health index for all methods. There is no strong correlation between health index and age of transformers as the value of health index of the transformer is reflected by the operation and the loading history of a transformer. Assessment Model A and B show the highest and second highest value of r^2 compared with other methods. This is due to the large weighting factor assigned to dissolved gas analysis, oil quality analysis, and furan analysis. The low value of r^2 for Assessment Model C and D is due to lack of data for the input.

Based on the transformer health index application, it helps asset managers to monitor the condition of their assets. Further action such as maintenance, repair and upgrades, replacement, monitoring and contingency control can be undertaken based on the transformer health index. It will also increase the ability of utility company to provide the best electricity supply to the end user without interruption. This is because in developing countries, the need for continuous power supply is crucial for industrial, commercial and residential areas. Hence, through a comprehensive transformer health index method, there will be no unplanned outage during in-service. Further investigation is needed to improve the accuracy of the transformer health index.

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REFERENCES

Abiri-Jahromi, A., Parvania, M., Bouffard, F., & Fotuhi-Firuzabad, M. (2013). A Two-Stage Framework for Power Transformer Asset Maintenance Management - Part I: Models and Formulations. *IEEE Transactions on Power Systems, 28*(2), 1395–1403. http://doi.org/10.1109/TPWRS.2012.2216903

Abiri-Jahromi, A., Parvania, M., Bouffard, F., & Fotuhi-Firuzabad, M. (2013). A Two-Stage Framework for Power Transformer Asset Maintenance Management - Part II: Validation Results. *IEEE Transactions on Power Systems, 28*(2), 1404–1414. http://doi.org/10.1109/TPWRS.2012.2216904

Abu-Elanien, A. E. B., & Salama, M. M. A. (2010). Asset Management Techniques for Transformers. *Electric Power Systems Research, 80*(4), 456–464. http://doi.org/10.1016/j.epsr.2009.10.008

Abu-Elanien, A. E. B., Salama, M. M. A., & Ibrahim, M. (2011). Determination of Transformer Health Condition Using Artificial Neural Networks. In *International Symposium on Innovations in Intelligent Systems and Applications* (pp. 1–5).

Abu-Elanien, A. E. B., Salama, M. M. A., & Ibrahim, M. (2012). Calculation of a Health Index for Oil-Immersed Transformers Rated Under 69 kV Using Fuzzy Logic. *IEEE Transactions on Power Delivery, 27*(4), 2029–2036. http://doi.org/10.1109/TPWRD.2012.2205165

Arshad, M., Islam, S., & Khaliq, A. (2014). Fuzzy Logic Approach in Power Transformers Management and Decision Making. *IEEE Transactions on Dielectrics and Electrical Insulation, 21*(5), 2343–2354. http://doi.org/10.1109/TDEI.2014.003859

Brittes, J. L. P., Nunes, E., Jardini, J. A., Magrini, L. C., & Kayano, P. S. D. (2014). T&ERTTA, Technical & Economical Real Time Transformer Assessment: An Innovative Approach on Power Transformer Life Cycle Management. In *Transmission and Distribution Conference and Exposition - Latin America (PES T&D-LA), 2014 IEEE PES* (pp. 1–6). http://doi.org/10.1109/TDC-LA.2014.6955186

Dominelli, N. (2004). Equipment Health Rating of Power Transformers. *Conference Record of the 2004 IEEE International Symposium on Electrical Insulation*, (September), 19–22. http://doi.org/10.1109/ELINSL.2004.1380501

Facilities Instructions, Standards and Techniques: Transformer Diagnostics (FIST 3-31). (2003).

Ghazali, Y. Y. Z., Talib, M. A., & Ahmad Rosli, H. (2008). Condition Assessment of Power Transformers in TNB Distribution System and Determination of Transformer Condition Index. In *Conference of the Electric Power Supply Industry (CEPSI)*.

Ghazali, Y. Y. Z., Talib, M. A., & Ahmad Rosli, H. (2009). TNB Experience in Condition Assessment and Life Management of Distribution Power Transformers. In *Electricity Distribution - Part 1, 2009. CIRED 2009. 20th International Conference and Exhibition on* (pp. 1–4).

Haema, J., & Phadungthin, R. (2012). Condition Assessment of the Health Index for Power Transformer. In *Power Engineering and Automation Conference (PEAM), 2012 IEEE* (pp. 1–4). http://doi.org/10.1109/PEAM.2012.6612413

Haema, J., & Phadungthin, R. (2013). Development of Condition Evaluation for Power Transformer Maintenance. In *4th International Conference on Power Engineering, Energy and Electrical Drives* (pp. 620–623).

Jahromi, A. N., Piercy, R., Cress, S., Service, J. R. R., & Fan, W. (2009). An Approach to Power Transformer Asset Management Using Health Index. *IEEE Electrical Insulation Magazine, 25*(2), 20-34. http://doi.org/10.1109/MEI.2009.4802595

Ma, H., Saha, T. K., Ekanayake, C., & Martin, D. (2015). Smart Transformer for Smart Grid-Intelligent Framework and Techniques for Power Transformer Asset Management. *IEEE Transactions on Smart Grid, 6*(2), 1026–1034. http://doi.org/Doi 10.1109/Tsg.2014.2384501

Malik, H., Azeem, A., & Jarial, R. K. (2012). Application Research Based on Modern-Technology for Transformer Health Index Estimation. In *International Multi-Conference on Systems, Signals and Devices, SSD 2012 - Summary Proceedings* (pp. 18–21). http://doi.org/10.1109/SSD.2012.6198012

Naderian, A., Cress, S., Piercy, R., Wang, F., & Service, J. (2008). An Approach to Determine the Health Index of Power Transformers. In *International Symposoium on Electrical Insulation (ISEI 2008)* (pp. 192–196). http://doi.org/978-1-4244-2092-6/08

Trappey, A. J. C., Trappey, C. V., Ma, L., & Chang, J. C. M. (2015). Intelligent Engineering Asset Management System for Power Transformer Maintenance Decision Supports Under Various Operating Conditions. *Computers and Industrial Engineering, 84*, 3–11. http://doi.org/10.1016/j.cie.2014.12.033