Journal of Engineering, Science and Technology
ISSN: 2714-2396, Volume 7 Issue 1

DEVELOPMENT OF A TIER 1 TRANSFORMER CONDITION INDEX CALCULATOR

S.T. Olusanya [1*], S.T. Wara [2], I.A. Adejumobi [3] and A.J. Olanipekun [3]

[1] Transmission Company of Nigeria, Lagos Region, Nigeria
[2] Havilla University, Nde, Nkom, Cross River
[3] Electrical and Electronics Department, College of Engineering,
Federal University of Agriculture Abeokuta (FUNAAB), Abeokuta, Nigeria
E-mail: taiwosolomon2001@yahoo.com, docwarati@gmail.com, adejumobiia@funaab.edu.ng, olanipekunaj@funaab.edu.ng, taiwosolomon2001@yahoo.com (Corresponding author)

Received Date: 15th May 2024 Accepted Date: 12th July 2024 Published Date: 15th Sept., 2024

ABSTRACT

Transformer failure could occur due to poor maintenance culture and bottlenecks involved in fault analysis and repair. In Nigeria, these bottlenecks are due to an insufficient supply of experienced maintenance experts and poor knowledge of transformers' condition and maintenance history. Hence, there is a need to develop a system for maintaining and knowing the conditions of transformers. This work developed a transformer index calculator using a heuristic method employing an expert knowledge base and standardised rules with an algorithm in Microsoft C Sharp 2010 programming language. The Condition Index Calculator (CIC) is an integral part of a developed Transformer Repairs and Diagnostic System (TRDS) software. The condition index value of transformers ranges between 0 and 10. The transformer fault conditions and test results data were collected from the Auchi Business Unit of Benin Electricity Distribution Company (BEDC). The data was analysed using transformer test status in the substations. BEDC did not indicate the degradation level of oil analysis, and the history of operation and maintenance (O&M) was poorly documented. CIC was used to determine the condition of the transformers. The result was similar to the BEDC results but with more specific results.

Keywords: Transformer, transformer condition index, diagnostic system, operational conditions, BEDC.

1. INTRODUCTION

During operation, electrical equipment in the grid may be damaged due to external (lightning, overvoltage) and internal (ageing of the insulation system) causes. Assessing the condition of this equipment to avoid premature failure is a very important topic due to investment and reliability issues [1-3]. The power transformers are the foremost important and costly hardware within the electrical transmission frameworks. The average life of transformers in the power system is about 25 to 30 years. It is not economical to change such equipment just because it is old. The operator needs to know and manage more insulation information, as the state of the insulation determines the waiting time [4-5].

Assessing the condition of a transformer requires not only integrating known artificial intelligence (AI) technology but also exploiting relationships between measured data. [6-8]. It was maintained that a transformer can only operate efficiently, reliably and economically if we

know its actual state by developing all the necessary information [4]. Operational reliability is primarily affected by the quality of the insulation.

A realistic health index formulation method was used for power transformers using readily available data [9]; [7]. The calculation of this health index not only takes into account typical test results such as dissolved gas analysis (DGA), oil quality and power factor but also takes into account other parameters such as load history, age, etc. Using multi-criteria analysis, it combines different factors into a condition-based health index.

2. MATERIALS AND METHOD

The condition index calculator, which was developed for power transformers, is presented in this paper. Expert knowledge-based and standardized rules were employed using the heuristic method. A heuristic technique is a problem-specific approach that employs a practical method that often provides sufficient accuracy for the immediate goals. An algorithm using Microsoft C Sharp 2010 as a programming language was used to develop software. The software was developed by Transformer Repairs and Diagnostic System (TRDS). Data on transformer fault conditions, age, excitations current and PF test results, analysis of insulating oil and history of operation and maintenance for 2010 were collected from nine (9) substations in the Auchi Business Unit of Benin Electricity Distribution Company (BEDC). These Transformer data were applied to the developed software to get the condition index of the transformers. The result was then compared with the results of the BEDC.

2.1. Transformer Repairs and Diagnostic System (TRDS)

TRDS addressed faults and symptoms in the major parts of transformers, including the cooling system, magnetic core, electric circuit, and condition index calculator. The user could find the faults by choosing the symptoms and the symptoms by indicating the faults. General tests, special tests, and maintenance procedures, according to Ewetumo [10], were incorporated into the software. However, for the purpose of this article, only the condition index calculator is discussed.

2.2. Condition Index Calculator (CIC)

The condition index calculator was designed as a tab on the TRDS window. It was based on the Tier 1. Hydropower plant engineers commonly consider the following four health indicators to provide a solid basis for assessing the condition of transformers [11]:

i. Analysis of the Insulating Oil
ii. Excitation Current and Power Factor Tests,
iii. History of Operation and Maintenance (O &M)
iv. Age

Numerical scores are assigned to each condition indicator, which is then weighted and summed to determine the Transformer Condition Index. Tables 1-4 show the results of the operation and maintenance history scoring, age, scoring insulating oil analysis, and excitation current and power factor test scoring, with their appropriate condition indicator score, respectively [11]. In Table 3, the Total dissolved combustible Gas Generation Rate and Individual Combustible Gas generation are represented by TDCGGR and ICGGR, respectively. Table 5 shows the procedure

for calculating the final Condition index of the transformer. The Condition Index tab contains the portion for selecting the type of analysis required. There are four major analyses necessary for the condition index to be calculated. They are insulation oil analysis, power factor and excitation analysis, operation and maintenance history analysis and age analysis. Selection of the condition of each of the analysis automatically assigns a numerical value to the selected condition.

Table 1: Operation and Maintenance History Scoring [11]

History Results	Condition Indicator score
Operation and maintenance are normal	3
Some abnormal operating conditions experienced and or additional maintenance above normal occurring	2
Significant operation outside normal and/or significant additional maintenance is required, or forced outage occurs, or outages are regularly extended due to maintenance problems, or similar units are problematic	1
Repeated forced outages; maintenance is not cost-effective; major oil leaks and/or severe mechanical problems; or similar units have failed	0

Table 2: Age Scoring [11]

Age	Condition Indicator score
< 30 years	3
≥ 30 and < 45 years	2
≥ 45 years	1

Table 3: Insulating Oil Analysis Scoring [11]

Results	Condition Indicator Score
(TDCGGR < 30 ppm/month AND all ICGGR < 10 ppm/month. Exceptions: CO generation < 70 ppm/month AND acetylene (C2H2) generation rate=0 ppm) **AND** (2 FAL Furans ≥ 150ppb (part per billion))	3
(TDCGGR ≥ 30 and < 50 ppm/month AND all ICGGR <15 ppm/month. Exceptions: CO generation < 150 ppm/month AND acetylene (C2H2) generation rate=0 ppm) **OR** (2 FAL Furans ≥ 150 ppb and < 200 ppb)	2
(TDCGGR ≥ 50 and < 80 ppm/month AND all ICGGR <25 ppm/month. Exceptions: CO generation < 350 ppm/month AND acetylene (C2H2) generation rate <5 ppm/month) **OR** (2 FAL Furans ≥ 200 ppb and < 250 ppb)	1
(TDCGGR ≥ 80 ppm/month AND any ICGGR >50 ppm/month. Exceptions: CO generation < 350 ppm/month AND acetylene (C2H2) generation rate <10 ppm/month) **OR** (2 FAL Furans ≥ 250 ppb)	0

Table 4: Power Factor and Excitation Current Test Scoring [11]

Test	Condition Indicator Score
Power factor results normal (Good -G) AND	3

Normal excitation current values and patterns compared to either phases and prior tests Power factor show minor degradation (Deteriorated -D) OR Minor deviation in excitation current values and patterns compared to other phases and prior tests	2
Power factor results shoe significant deterioration (Investigate-I) OR Significant deviation in current values and patterns compared to other phases and prior tests	1
Power factor results shoe severe deterioration (Bad- B) OR Severe deviation in current values and patterns compared to other phases and prior tests	0 (may indicate serious problem requiring immediate evaluation, additional testing, consultation with experts and remediation prior to re-energization

Table 5: Tier 1 Transformer Condition Summary [11]

S/N	Condition Indicator	Score	Weighing Factor	Total score
1	Oil Analysis (Score must be 0, 1,2, or 3)		1.143	
2	Power Factor and Excitation Current Tests (Score must be 0, 1,2, or 3)		0.952	
3	Operation and Maintenance History (Score must be 0, 1,2, or 3)		0.762	
4	Age (Score must be 1,2,or 3)		0.476	
	Tier 1 Transformer Condition Index (sum of individual Total Score) (Condition index should be between o and 10)			

The following equation (1) for calculating transformer condition index (CI) was obtained from Table 5.

$$CI = \left(\frac{W_o S_o + W_{pf} S_{pf} + W_{om} S_{om} + W_a S_a}{4}\right) \quad (1)$$

Where,

W_o = oil analysis weighting factor, S_o = oil analysis score, W_{pf} = power factor weighting factor, S_{pf} = power factor score, W_{om} = operation and maintenance history weighting factor S_{om} = operation and maintenance history score, W_a = age weighting factor, and S_a = age score

3. RESULTS AND DISCUSSION

The CIC assigned 0 when {TDCG generation rate ≥ 80 and < 80 ppm/month AND all individual combustible gas generation rates < 50 ppm/month was selected as shown in Figure 1a. Numerical value of 0 was assigned when Power factor results show severe degradation. (Deteriorated – D) OR severe deviation in current values and patterns compared to other phases and prior tests in Figure 1b. With some significant operation outside normal experienced and/or significant additional maintenance is required selected in the Operation and maintenance history, the CIC assigned 1 to the analysis as shown in Figure 1c. Likewise, when age >30 years was selected, CIC assigned the numerical value of 2 to the analysis result. This is shown in Figure 1d.

Considering Figs. 1a-1d, Condition Index (CI) scores for analysis of insulating oil, excitation current and power factor, operation and maintenance history and age of the transformer are shown respectively. Afterwards, the condition Index for the transformer was calculated using the calculate button. Figure 2 shows the total Condition Index calculation for the four tests. As shown in Figure. 2, when the calculate condition index button was engaged, the result of the condition index was given as 5.999 which is between 1 and 10 as stipulated in Table 5 showing Tier1 transformer.

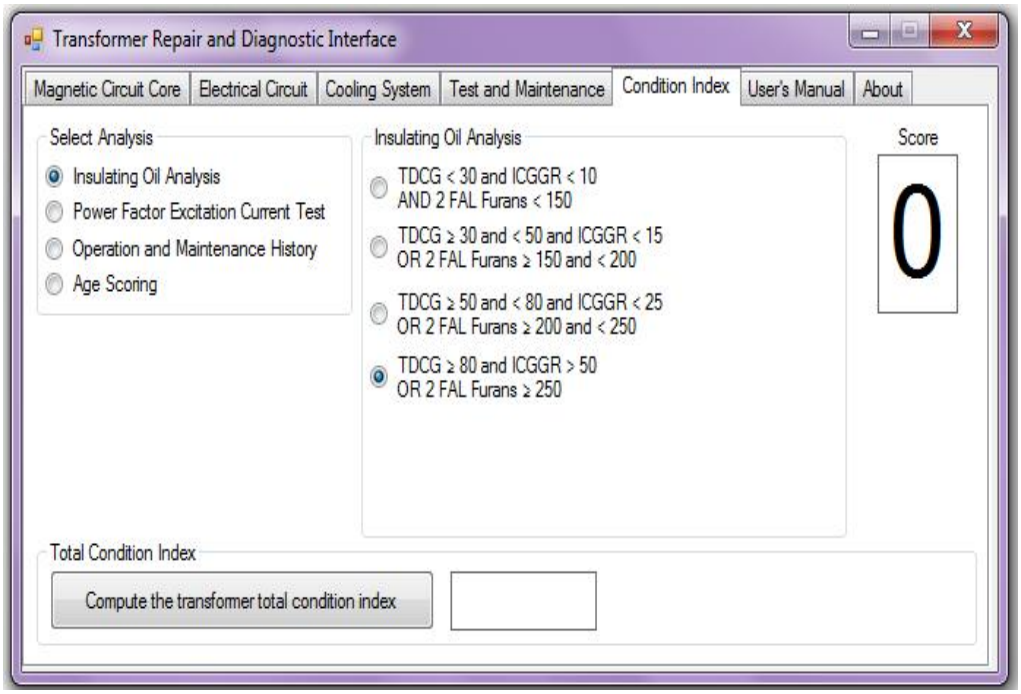

Figure 1a: condition Index score for Insulating Oil Analysis

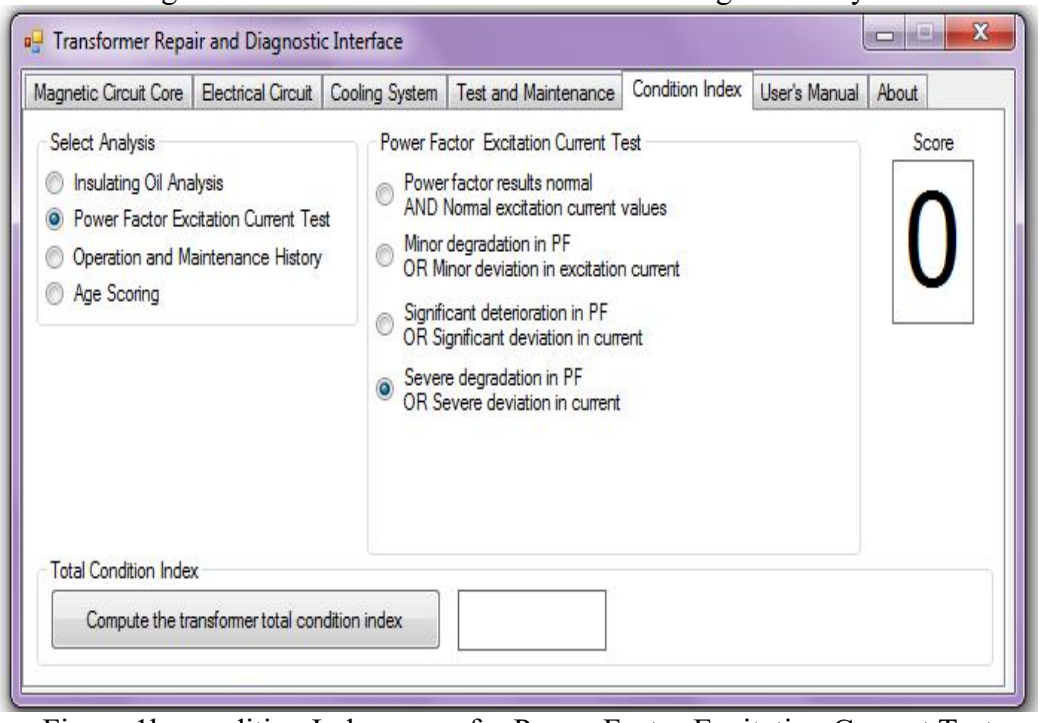

Figure 1b: condition Index score for Power Factor Excitation Current Test

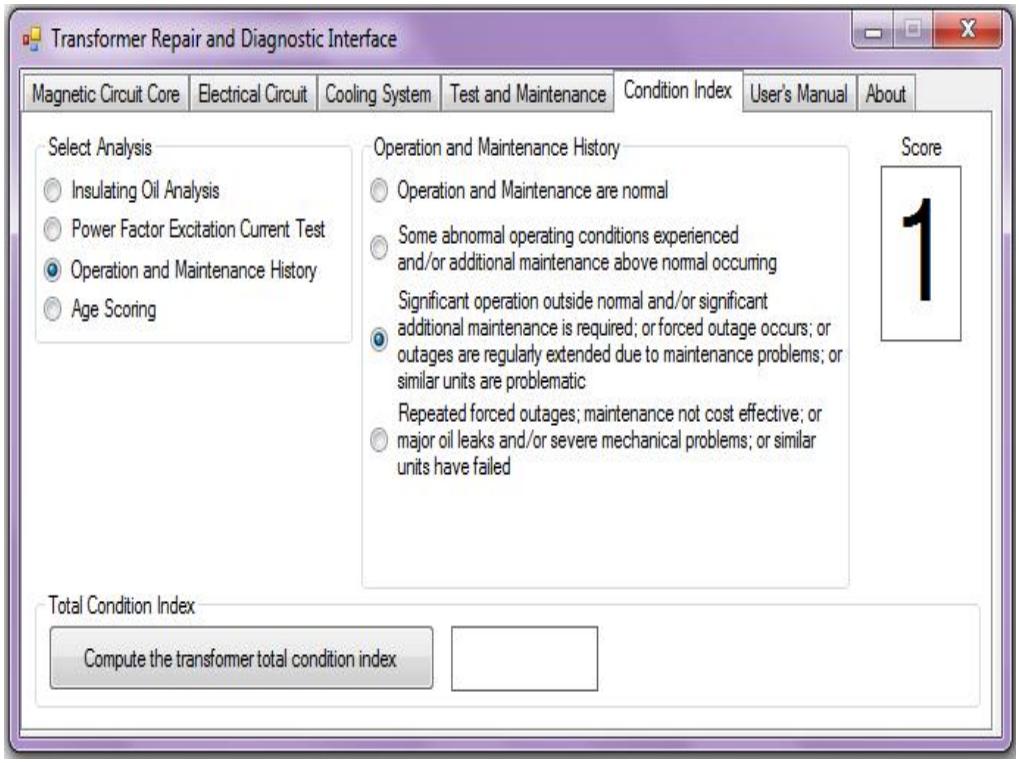

Figure 1c: Condition index score for Operation and machine history

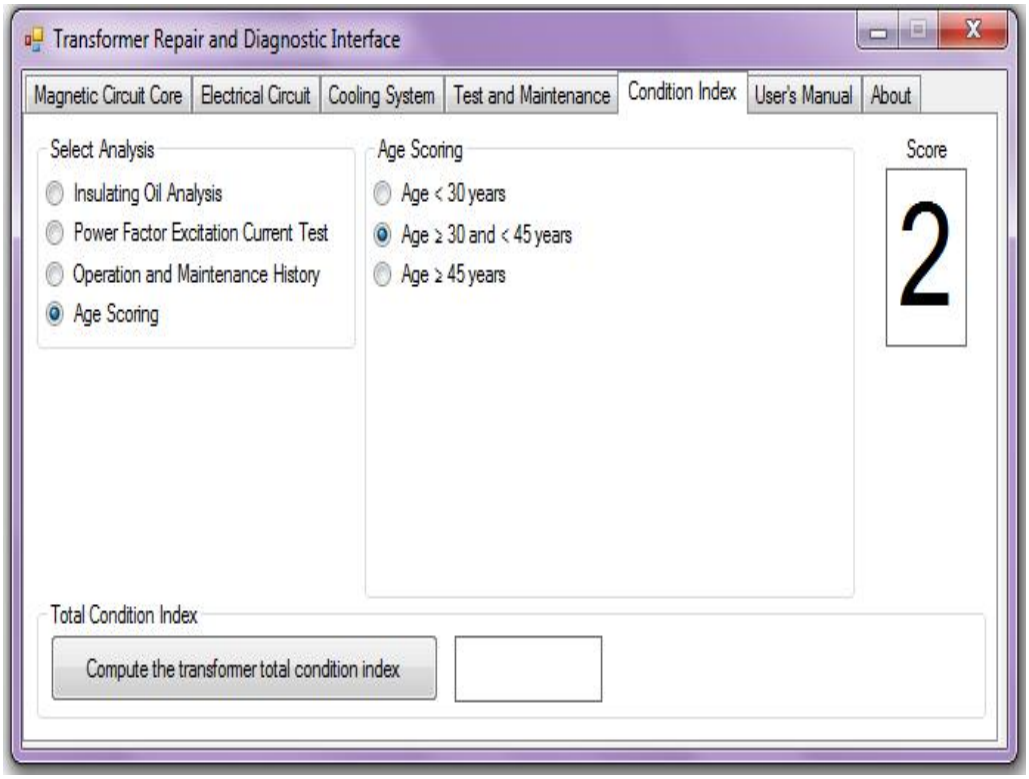

Figure 1d: condition Index score for Age Scoring

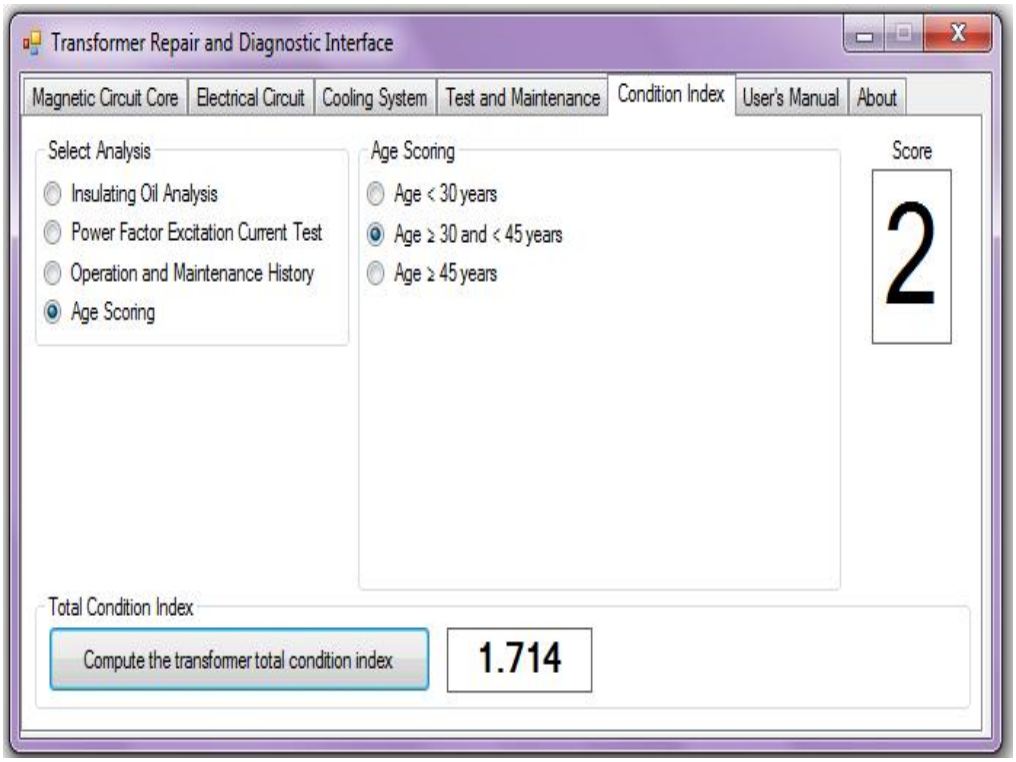

Figure 2: CIC of TDRS interface showing Total Condition Index Score for a Transformer condition summary.

Table 6: Comparison of CIC and BEDC Remarks for 2010

S/N	Name of substation	Total condition index score	Year of Manufacture	TRDS Remark	BEDC Remarks
1	Igarra 2.5MVA, 33KV/11KV	7.142	2009	Good	Good
2	Ugboshi Afe 100KVA, 11KV/415V	4.000	1974	Repair	Repair or Replace
3	Bees Electrical 500KVA, 33/415KV	4.476	2005	Repair	Inconclusive
4	Olele junction 300KVA, 11/415KV	4.476	2005	Repair	Inconclusive
5	DASSCOLLIN 300KVA, 11/415KV	1.714	1977	Replace	Repair or Replace
6	ABDUL OROH 200KVA, 11/415KV	4.285	1997	Repair	Inconclusive
7	EGBETUA VILLAGE 50KVA, 11/415KV	1.714	1977	Replace	Repair or Replace
8	EXPRESS ROAD 200KVA, 11/415KV	4.285	1999	Repair	Repair or Replace
9	ATTE VILLAGE 200KVA, 11/415KV	4.476	1990	Repair	Inconclusive

FigureThe developed Condition Index Calculator was applied to DASSCOLLIN Substation (300KVA 11/415KV) Transformer in Auchi Business Unit as shown in Figures 1a-1d. The

insulating oil analysis score, power factor and excitation current score, O&M history score and age score gave 0,0,1,2 respectively. Table 6 shows the Total condition index of the transformer as 1.714. The conditions were chosen using the worst situation for insulating oil analysis and Power factor, which the transformer failed as shown in Figure 1a because these analyses were not normally done to give the grade or degree of their deterioration.

TRDS was also applied to Igarra Injection Substation (2.5MVA 11/415KV) Transformer in Auchi Business Unit as shown in Table 6. The insulating oil analysis score, power factor and excitation current score, O&M history score and age score gave 2,2,2,3 respectively. The Total condition index of the transformer was 7.142. This substation was chosen for the test because it was the only one that passed all tests conducted on it, though with slight deviations.

4. CONCLUSION

The application of transformer condition index is a critical issue in Nigeria. Over the years, The Federal Government has spent several billions of naira on power sector without the commensurate result. It was also found out that the conditions of transformers were not ascertained until the transformers broke down. Hence, the need to incorporate transformer condition index in the development of an application that will address the problem. An application called Transformer Repairs and Diagnostics system (TRDS) which incorporated Condition Index Calculator (CIC) was developed to address these problems. The software was tested by applying it to different substation in Auchi business unit. The results confirmed an earlier test carried out manually on the transformer by BEDC. However, it gave more specific result and room for indicating various deterioration levels of different transformers. The CIC will find application in Transformer installation, Maintenance and Repair Companies, Works Department of various establishments as well as the BEDC.

ACKNOWLEDGEMENT

The authors would like to extend our heartfelt appreciation to Mrs. Tomi Omotayo nee Fasidi for her generous financial contribution towards the success of this research. I am also deeply grateful to Dr. Adetomi Adewale for his invaluable technical assistance throughout the research process and the Federal University of Agriculture Abeokuta for giving the platform for the research.

REFERENCES

[1] Tanasescu, G., Notingher, P.V., Dragomir, O., Gorgan, B. and Voinescu, L., 2013. Health index calculation of electrical equipments using DiagConsole software. *Advanced Topics in Electrical Engineering (ATEE), 2013. 8th International Symposium* Bucharest on 23-25 May 2013 .1 - 6

[2] Bendriss, B. 2019. Overvoltages Evaluation in Transformation Substations under Lightning effect. People's Democratic Republic of Algeria Ministry of Higher Education and Scientific Research, Larbi Ben M'Hidi University, Oum El Bouaghi (Algeria) Faculty of Sciences and Applied Sciences Department of Electrical Engineering. *A graduation thesis Submitted in partial fulfillment of the requirements for the degree of Master Option: Electrical Power System*.

[3] Christina, A.J., Salam, M. A., Rahman, Q. M., Wen, F., Ang, S. P., & Voon, W. 2018. Causes of transformer failures and diagnostic methods – A review. *Renewable and Sustainable Energy Reviews,* 82: 1442–1456. doi:10.1016/j.rser.2017.05.165

[4] Voros, C., Nemeth, B. , Kiss, I. and Berta, I. , 2011. Transformer Status Indicator (TSI) as a new expert system for integrating the diagnostic results of power transformers. *Energetics (IYCE), Proceedings of the 2011 3rd International Youth Conference*, Leiria on 7-9 July 2011. 1 - 5

[5] Li, S., Li, X, Cui, Y., Li, H., 2023. Review of Transformer Health Index from the Perspective of Survivability and Condition Assessment. *Electronics 2023*, 12(11): 2407; https://doi.org/10.3390/electronics12112407

[6] Lee, L, Xie L., Zhang D., Yu B., Ge Y. and Lin F., 2013. Condition assessment of power transformers using a synthetic analysis method based on association rule and variable weight coefficients. Dielectrics and Electrical Insulation*, IEEE Transactions*. 20 (6): 2052 - 2060

[7] Rediansyah D.; Prasojo R.A.; Suwarno, 2021. Study on Artificial Intelligence Approaches for Power Transformer Health Index Assessment. 2021 *International Conference on Electrical Engineering and Informatics (ICEEI)*. 12-13 October.

[8] Wang, J., Zhang, X., Zhang, F., Wan J., Kou, L. and Ke, W., 2022. Review on Evolution of Intelligent Algorithms for Transformer Condition Assessment. *Front. Energy Res*. 10:904109. doi: 10.3389/fenrg.2022.904109

[9] Naderian, A., S. Cress, R. Piercy, F. Wang and J. Service, 2008. An Approach to Determine the Health Index of Power Transformers. Electrical Insulation, 2008. ISEI 2008. *Conference Record of the 2008 IEEE International Symposium on 9-12 June 2008*. Vancouver, BC. Page(s):192 - 196.

[10] Ewetumo, A.A (2006).Transformer- test and inspection for faults: Transformer Causes, Prevention of Failures and Maintenance Procedure. *Nigerian Society of Engineers Workshop in Collaboration with BEDC*. November 2006.

[11] US Army Corps of Engineers (USACE), 2006. Hydro Plant Risk FigureAssessment Guide. *Appendix E5: Transformer Condition Assessment*.