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Multi-expert GMM decision support system with AHP method for determining weight of transformer oil insulation quality index

Ekojono*, Havenia Ventina Banjarnahor, and Endah Septa Sintiya

Politeknik Negeri Malang, Information Technology Department, Malang, Indonesia, 65141

Abstract - The transformer is important and quite central in the power system for distributing energy from generators to consumers through electrical substations. Good transformer oil isolation is needed to protect the transformer to function optimally and prevent fatal interference. Over time, insulating oil experiences aging which can cause transformer damage and disruption in energy distribution to consumers. There are three things that affect the condition of transformer oil insulation, namely chemically testing for acidity, sediment (SED) and water content, from an electrical point of view testing for breakdown voltage (BDV) and testing dielectric dissipation factor (DDF), and from a physical point of view, color, and interfacial tension (IFT) tests are carried out. In dealing with this problem, a Decision Support System (DSS) is needed to calculate the oil quality index based on the given parameters. The method used is Analytical Hierarchy Process (AHP) with multi-expert GMM. The results show that the system is running well, and the calculation method is appropriate. Tests show 100% accuracy in comparing manual calculations with the Confusion Matrix system. Users give an average satisfaction of 92.94%. In conclusion, this system effectively meets the need and helps to determine the quality index of insulating oil in transformers.

Keywords: AHP, decision support system, multi-expert, transformer, transformer oil insulation

1 Introduction

Electrical energy is one of the basic needs that is important in supporting community activities. Currently, the development of economic, industrial and technological growth is very fast, thereby increasing the consumption of electrical energy by society [1]. In distributing electrical energy, a tool is needed that plays a very important role in the electrical system, namely a transformer. The transformer functions to change one voltage level to another voltage level by increasing the voltage or decreasing the voltage [2]. Transformers are the most important and central part of the electric power system to meet people's electricity needs.

To maintain its performance and prevent failure, the quality of the transformer oil insulation needs to be maintained so that it works optimally and is free from interference. The life of a transformer is greatly influenced by loading, insulation and surrounding temperature [3]. One of these insulations is transformer oil which functions as an insulator and coolant for the transformer so that anticipating a large increase in temperature in the transformer can cause the transformer to become hot, the transformer oil will expand and increase in volume and reduce the capacity of the transformer

*Corresponding author: ekojono@polinema.ac.id

and vice versa so that the longer the oil insulation experiences aging. Contaminated oil conditions (oxidation) result in a decrease in its insulating ability so that the oil will produce acid. If the acid produced is mixed with air and high temperatures it will result in a hydrolysis process [4] which if there is interference can have fatal consequences for the transformer. When a transformer is damaged it can disrupt the distribution of electrical energy to consumers and also takes a very long time to repair and high costs to replace.

1.1 Literature Review

Based on the results of research with the research title "Development of Analytic Hierarchy Process Technique in Determining Weighting Factor for Power Transformer Health Index" research was obtained, namely obtaining a calculation for determining weighting with the health index. There are three factors proposed, namely oil quality factor, faults factor, and paper condition factor. Based on the results of calculations using AHP, the order of factors that got the highest weight results, namely faults factor with DGA parameters got a weight value of 0.560, paper condition factor with parameter order 2FAL with a weight of 0.261, age with a weight of 0.242, and CO2&CO with a weight of 0.203, and oil quality factor of the 7 parameters, the order of dielectric dissipation factor (DDF) results is the highest with a weight of 0.251 [5].

Based on the results of research with the research title "An Approach of The Analytic Hierarchy Process to Acquire The Weighting Factor of High Voltage Circuit Breaker Health Index" resulted in research with index weighting on circuit breakers using AHP. With two factors, namely the condition assessment factor with five parameters and the profile assessment factor with four parameters. Based on AHP calculations, the highest final weighting, namely the profile assessment factor with the parameter anomaly findings, gets a final weight of 0.303 and CB Life (Age) with a weight of 0.250, and the condition assessment factor with the parameter contact resistance gets a final weight of 0.231 [6].

Based on a research journal with the research title "Decision Support System for Selection of Programming Languages Using the Analytical Hierarchy Process Method" it is concluded that from the problem of selecting a programming language in creating a web, the calculation results are among the criteria of simple/easy, powerful, popular, and portable/cross platform. which is the most important criterion is simple/easy. Meanwhile, the results of calculations based on alternatives between JavaScript, PHP, Python, C++, and Java show that the JavaScript alternative which is the best studied alternative produces a JavaScript alternative. The final weight and ranking results based on these calculations with JavaScript, PHP, Python, Java, and C++ alternatives are, 0.3268, 0.2181, 0.2181, 0.1248, and 0.1117 [7].

Based on the results of research with the research title "A Multiple Expert Consensus Model For Transformer Assessment Index Weighting Factor Determination" the conclusion obtained is by utilizing several respondents or multi-experts in determining the weighting factor for the health index of power transformers with five experts who use the geometric mean method to obtain consensus matrix and will be aggregated using AHP. The results of calculations using these two methods can show that the proposed method can be implemented using multi-expert power transformer assessment index weighting factors [8].

Based on the results of research with the research title "Evaluating Weight Priority on Green Buildings Using Fuzzy AHP", the conclusion obtained was by utilizing many respondents in determining green buildings in Boyolali district government buildings. Because the number of respondents used was more than one, to produce answers that represented all respondents, the geometric mean method was calculated to determine priority weights. The criteria used in determining weight are energy conservation and efficiency, water conservation and efficiency, air quality and thermal comfort, and operation management and maintenance. Each criterion has sub-criteria, totaling twenty-three sub-criteria. Criteria calculations are used using two methods, namely geometric mean on crisp AHP and geometric mean on TFN fuzzy AHP. The geometric mean calculation functions in the calculation results of the two methods are different, the highest global weight obtained by respondents who are consistent in the criteria of 20% and respondents who are consistent in the sub-criteria of 25% in the first method is produced by the sub-criteria of the energy and efficiency criteria of 0, 0706. Meanwhile, in the second method the highest global weight is produced by on site renewable energy of 0.0772 [9].

2 Materials and methods

2.1 Data Collection

Data collection is carried out directly by providing an excel file containing criteria and sub-criteria (parameters) relating to the condition of the oil insulation in the transformer so that the criteria and sub-criteria (parameters) whose values are already listed are filled in by the working expert. in the maintenance sector or transformer expert section. The following is an example of the contents of an Excel file from a multi-expert assessment. The names of the experts who gave grades in the order of expert 1, expert 2 and expert 3 were Achmad, Ojan, and Mahendra.

2.2 Data Processing

AHP is a decision making process whose measurements use pairwise comparisons to find a ratio scale [10], provides the weight value of a criterion [11] so that it can identify the relative priority of each criterion and alternative. Hierarchies can help deal with complex and unstructured issues so that they are divided into several groups and arranged into a hierarchy. The advantages of the AHP in explaining decision making: hierarchical structure from criteria to sub-subs, considering validity to tolerating inconsistencies, involving expert decision makers, and calculating the durability of sensitivity analysis [12]. The parameters used are BDV, water content, acidity, IFT, color, DDF, and SED [13]. A pairwise comparison matrix is utilized to compare each parameter based on two criteria, namely Measurement Reliability (MR) and Criticality (CR). Then, the outcomes of the pairwise comparisons were checked using comparison consistency. After that, a combination process is executed to derive a consensus matrix, which is subsequently aggregated again through AHP. The weighting factor is determined by the results of the consensus matrix and then using AHP. The stages of preparing the analytical hierarchy process begin with the goals or objectives, followed by the first level criteria, and followed by sub-criteria. The following are the basic principle stages of the AHP method:

2.2.1 Decomposition (creating a hierarchy)

Addressing complex systems involves breaking them down into smaller, supportive elements, arranging these elements in a hierarchical manner, and combining them so they can be easily understood.

2.2.2 Comparative judgment (assessment of criteria and alternatives)

Pairwise comparison is employed for assessing criteria and alternatives. In numerous instances, a scale ranging from 1 to 9 is the best scale for articulating opinions. The details of this scale are elaborated in Table 1 below.

Table 1. Pairwise Comparison Rating Scale

Intensity of Interest	Explanation
1	Both elements are equally important
3	One element is slightly more important than the other.
5	One element is more important than the others.
7	One element is clearly absolutely more important than the others.
9	One element is absolutely more important than the other elements.
2,4,6,8	Values between two values of adjacent considerations.

2.2.3 Synthesis of priority (determining priorities)

Pairwise comparisons need to be made for each criterion and each alternative. Adjustments to the relative comparison values and any alternative criteria can be made based on the provided assessments to generate weights and priorities. The calculation of weights and priorities involves the manipulation of matrices or the solution of mathematical equations.

2.2.4 Logical consistency

Consistency encompasses two interpretations: firstly, the grouping of similar objects together based on their similarity and relevance; and secondly, the evaluation of the relationship level between objects according to specific criteria.

The AHP method steps include:

1 Identify the problem and determine the desired solution, then develop a hierarchy of existing problems.

2 Determine element priority. Where to form pairwise comparisons according to the given criteria and parameters. The pairwise comparison matrix is filled with lift to represent the relative importance of one element to another.

3 Synthesis. Assessments regarding pairwise comparisons are collected or synthesized to obtain overall priorities. The things to do in this step are:

  a. Add the values of each column in the matrix. Divide each column value by the total sum of the respective column to obtain the matrix normalization.
  b. Sum the values of each row and divide them by the total number of elements to get the average value.
  c. Measure consistency. In decision-making, it is important to assess the existing level of consistency because users do not want decisions based on considerations with low consistency.
  d. Multiply each value in the first column by the relative priority of the first element, the values in the second column by the relative priority of the second element, and so on.
  e. Sum each row. Divide the row sum by the respective relative priority elements.

f. The above quotient is added together with the number of elements, and the result is called λ max.

g. Calculate the Consistency Index (CI)

$$CI=\frac{(\lambda maks-n)}{(n-1)} \quad (1)$$

Explanation:
n = the number of elements.

h. Calculate the Consistency Ratio (CR) using the formula:

$$CR=\frac{CI}{IR} \quad (2)$$

Explanation:CR = Consistency Ratio;
CI = Consistency Index
IR = Index Random Consistency

i. Checking Hierarchy Consistencya

j. If the value is greater than 0.1 or 10%, then the assessment of judgment data must be improved. If the consistency ratio calculation (CI/IR) results in a number less than or equal to 0.1, then the calculation results can be considered correct.

2.3 System Workflow

Based on Figure 1, there is a home display and a data page display on this system. The flow of the decision support system using the multi-expert GMM method for the transformer oil quality index using AHP is that when you open the application system it will display a home page containing an explanation of the application and the method and steps involved in the application. Then, if you click the continue button it will display the data page. Which on this page will input and manage the calculation of criteria and sub-criteria which can be input with many criteria and sub-criteria by many experts and manage the final weight results for each sub-criterion. Carry out the entire flow step by step, first the AHP calculation process is by inputting the criteria data by filling in the name of the criteria which can be input more than one, filling in the weight value of the criteria in the criteria matrix on a scale of 1-9, and providing the name of the expert then saving. If you want to add value with a different expert, select fill in the criteria matrix with new weight values then save with the name of the new expert.

After that, input all the criteria data with multi-expert, secondly, calculate the entire AHP calculation data from the number of experts using the geometric mean calculation process to combine the number of inputted expert assessments which will then be aggregated with the AHP calculation. After completing the criteria data calculation process, proceed to the second step with the data calculation process for the sub-criteria, which can be followed in the same flow as the AHP and GMM calculation process for the criteria.

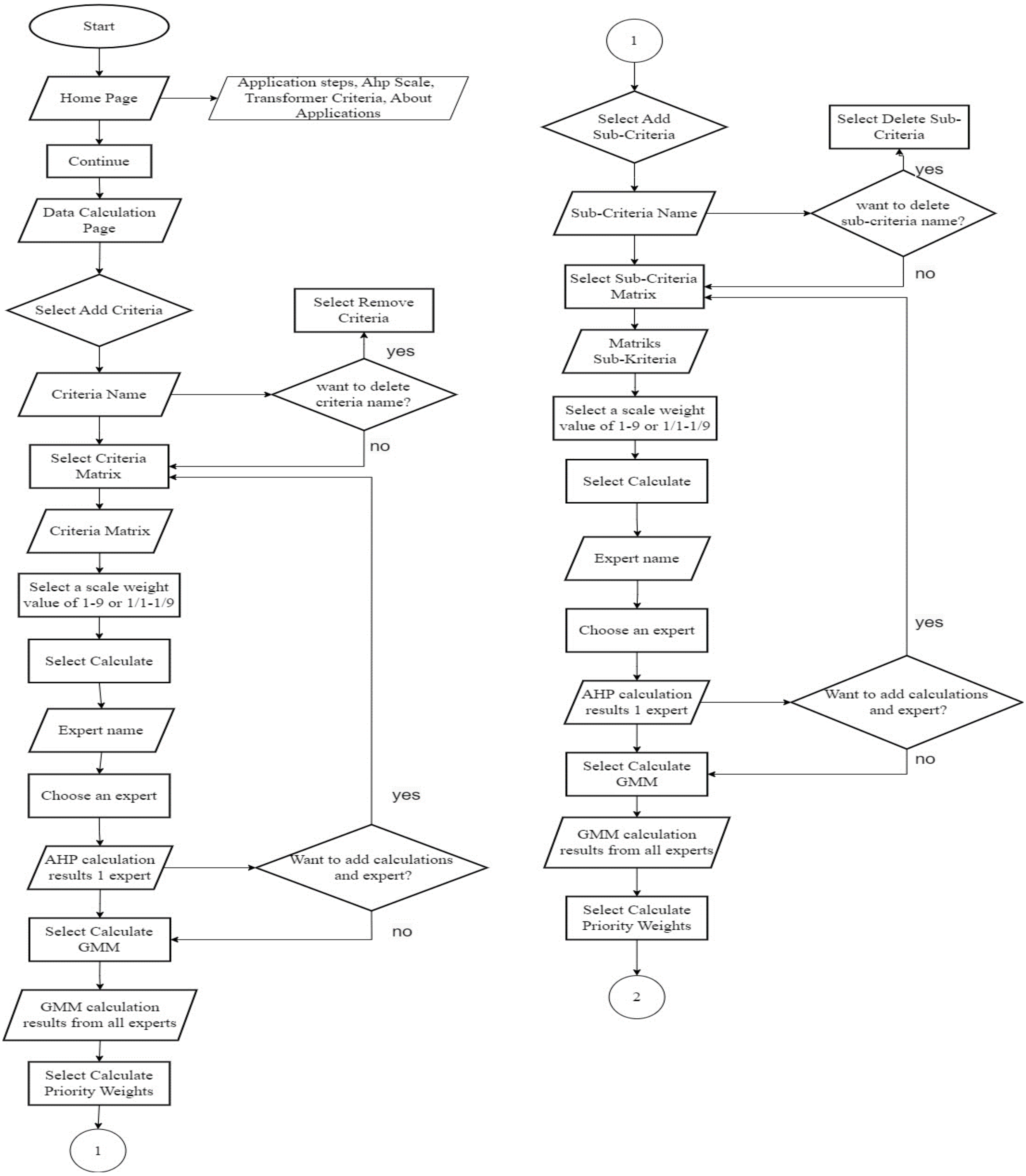

Fig. 1. Information Systems Work Flow (1)

The third process, after completing the data calculation process for the sub-criteria will continue on the final weight calculation process page. After that, you can see the priority weight results based on criteria and sub-criteria and display a graph as a visualization of the final weight calculation results. Finally, after completing the calculation process the user can save the data from the calculation results of the criteria, sub-criteria, and final weights in the form of a CSV file. If the user wants to delete the data, he can choose to reset the data, where the calculation data will be deleted and new data can be entered.

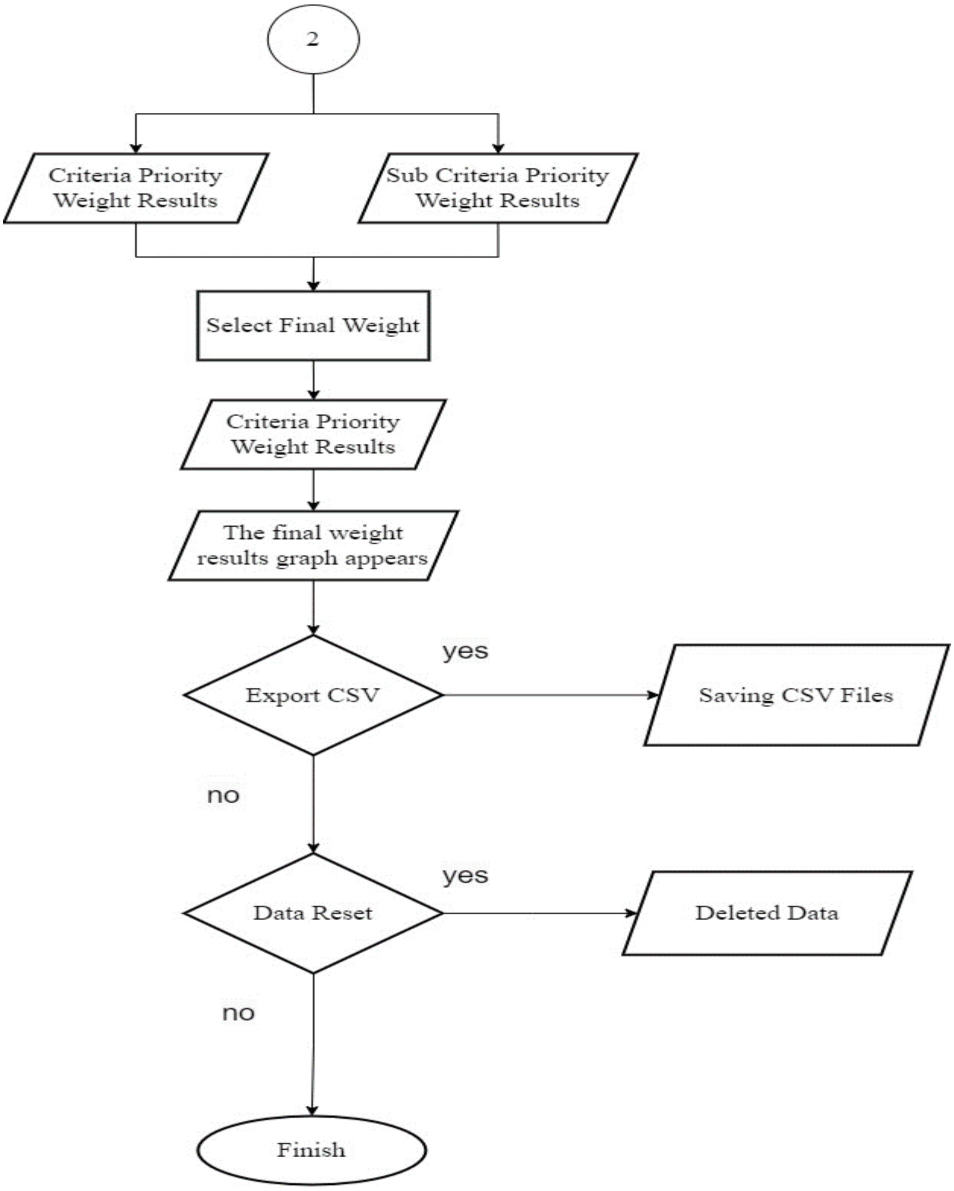

Fig. 2. Information Systems Work (2)

2.4 Need Analysis

Requirements that are related to the system are called functional requirements. Then, for non-functional requirements, these are limitations on the specified capabilities of the system.

2.5 System Testing

2.5.1 Confusion Matrix

The following is the Confusion Matrix formula for calculating the accuracy of the AHP method, where you can compare the results of calculations manually or using the following system:

$$A = \frac{(TP+TN)}{(TP+TN+FP+FN)} \times 100\% \quad (3)$$

2.5.2 User Acceptance Testing (UAT)

To calculate the results of this UAT, we use a Likert Scale with the following calculation formula::

$$\text{Index formula } \% = \frac{\text{Total Score}}{\text{Y}} \text{X}100\% \tag{4}$$

Explanation:
Y = Highest Likert score x number of respondents

2.5.3 Black Box Testing

This test is conducted to assess functionality, which will be done by observing the execution results through test data and examining the functionality of the developed application. Testing with this method aims to identify errors or bugs, specifically functional errors and interface errors. Send a message Free Research Preview. ChatGPT may produce inaccurate information about people, places, or facts.

3 Results and discussion

3.1 Calculation AHP Method

The data processing technique in this research uses the AHP method. Then, the calculation of the Geometric Mean Method (GMM) is performed to obtain a calculation matrix value from the numerous assessments by experts, which will be aggregated using the AHP method to obtain the final weighting ranking. The steps in the AHP method are as follows:

3.1.1 Create a hierarchy (decomposition) which can be seen in the image below:

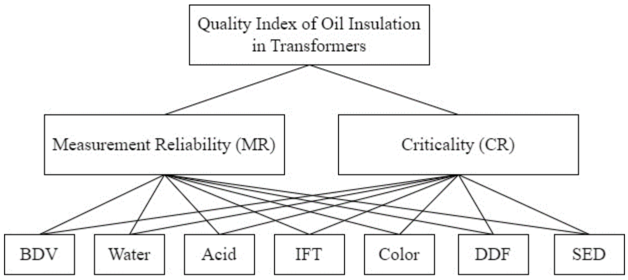

Fig. 3. Transformer Oil Insulation Quality Index

3.1.2 Criteria assessment (comparative judgement)

Criteria assessment is carried out using a pairwise comparison matrix with a scale of 1 to 9.

3.1.3 Logical consistency

There are several steps in this stage, namely:

1. The pairwise comparison matrix assessments are collected or synthesized.
2. Then, sum each column is divided by the pairwise comparison values to obtain the matrix normalization. Afterward, sum the values of each row and divide them by the number of criteria to obtain the average value, also known as eigenvalue or priority weight (WP).
3. After that, measure consistency by multiplying each first column value in the pairwise comparison assessment with the priority weight value in the first column, the second column

value in the pairwise comparison assessment with the priority weight value in the second column, and so on. The result of the calculation is called the hierarchical consistency value. Then the hierarchical consistency value is divided by the priority weight value to get the vector preference (VP) value.

4 Then, sum the preference vector results and divide them by the number of criteria, referred to as lambda (λ) max.
5 Next, calculate the consistency index (CI) based on equation 1 with the λ max value subtracted by the number of criteria. Then, divide the result by the number of criteria minus 1.
6 After that, calculate the consistency ratio (CR) based on equation 2 with the CI value divided by the random index consistency (IRC). Based on the number of criteria, which is two criteria, the IRC value is 0.
7 Finally, check the hierarchy's consistency. If the CR value is above 0.1, adjustments need to be made to the assessment. If the value is below 0.1, the calculation results can be considered correct or consistent. Based on the above calculation, the CR value obtained is 0, which is below the 0.1 threshold, indicating consistent results.

3.1.4 Assessment of sub-criteria (comparative judgment)

The assessment of sub-criteria based on the two criteria, Measurement Reliability (MR) and Criticality (CR), is done using pairwise comparison matrices with a scale of 1 to 9, as per Saaty's method. By performing the same calculation method, the consistency ratio (CR) based on pairwise comparison assessments of sub criteria for both criteria can calculate the AHP.

The AHP calculations for criteria and sub criteria are still based on the assessment of one expert, Achmad. Repeat the above steps for the assessments by the next two experts. In this research, there are three experts providing assessments. The second expert is named Ojan, and the third expert is named Mahendra. Here are the assessment results for Ojan and Mahendra.

1 The results of pairwise comparison evaluations by expert Ojan, and the pairwise comparison evaluations of sub criteria based on each criterion.
2 The results of pairwise comparison evaluations by expert Mahendra, and the pairwise comparison evaluations of sub criteria based on each criterion.

3.2 Result Calculation Results of the System

In this DSS, the AHP method is used to determine the transformer oil quality index. Subsequently, a consensus matrix will be obtained using the Geometric Mean Method (GMM), which will be aggregated again using AHP. The following are the calculation results of the AHP method in the system:

3.2.1 Create a Comparison Matrix

For each criterion, a comparison matrix will be formed as in Figure 4 below:

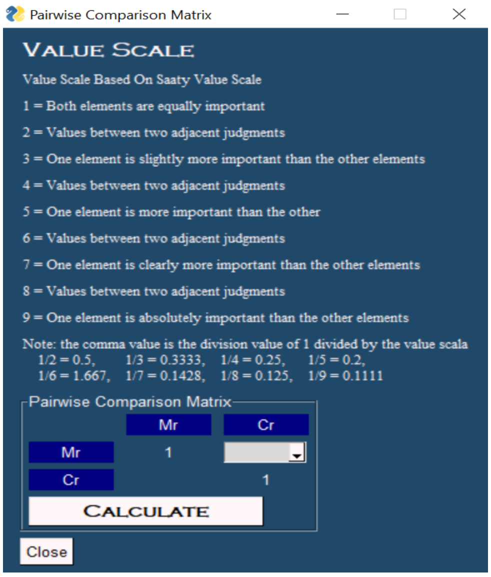

Fig. 4. Criteria Comparison Matrix

For each sub-criterion or parameter, a comparison matrix between criteria will be formed.

3.2.2 Calculating AHP

Each value entered in the pairwise comparison matrix of criteria and sub-criteria is given an expert name, so that you can find out the AHP results for each expert as by selecting the expert in the Select Expert dropdown.

After that, the AHP calculation displayed consists of, pairwise comparison matrix, normalized matrix, eigenvalue, weights, consistency hierarchy, preference vector, lambda max, CI, RI, and CR and you can find out whether the matrix is consistent or not.

3.2.3 Calculating GMM

The Geometric Mean Method calculation is carried out to combine all the assessments of each expert to display the results of a consensus matrix or a calculation that will be aggregated with the AHP calculation. After that, the criteria and sub-criteria that display the GMM calculation results consist of pairwise comparison consensus matrix, normalized matrix, eigenvalue, weights, consistency hierarchy, preference vector, lambda max, CI, RI, and CR and you can find out that the matrix is consistent or not.

3.3 Calculating Final Weights or Decision Making

Decision making calculations are based on a comparison of the multiplication calculation of criteria weights with sub-criteria weights (parameters). Among the results of the sub-criteria (parameters) will produce different final weight values. By having a large or high weight value, the weight is considered critical or important compared to parameters with a weight value below it. The calculation results can be seen in Figure 5 below:

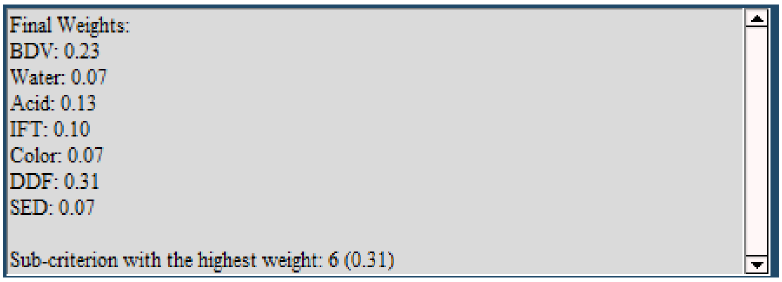

Fig. 5. Final Weight Results

3.3.1 Test Results

Testing is carried out on the system and user side. For the system side, testing uses a black box and the user side uses UAT. Meanwhile, testing the accuracy of the AHP method uses the Confusion Matrix.

a) *Method Testing*

The final weight results obtained from system calculations will be compared with the results of manual calculations carried out in Microsoft Excel. Comparison of manual (reality) and system calculation results is explained all data from boths result were appropriated. in Table 2 below:

Table 2. System and Manual Final Weights

Sub Criteria (Parameters)	Final Weights		Results
	Manual Results (Reality)	System Results	
BDV	0.23	0.23	Appropriate
Water	0.07	0.07	Appropriate
…	…	…	…
SED	0.07	0.07	Appropriate

The results of the calculations for the TP, TN, FP and FN values are in the Table 3 below.

Table 3. Determination of TP, TN, FP and FN values

Sub-criteria	Reality Results	System Results	TP	TN	FP	FN
BDV	0.23	0.23	Y	T	T	T
Water	0.07	0.07	Y	T	T	T
…	…	…	…	…	…	…
SED	0.07	0.07	Y	T	T	T
Total			7	0	0	0

Where Y is "Yes Appropriate", which means that the results of the comparison of the final weight results in reality (reality) and the system are appropriate. Meanwhile, T is "None", which means that the results of the final weight calculation in reality and the system do not match. Based on the TP, TN, FP and FN values in Table 3, the level of accuracy obtained using equation 4 is as follows:

$$A = \frac{(TP+TN)}{(TP+TN+FP+FN)} \text{ x } 100\% = \frac{(7+0)}{(7+0+0+0)} \text{ x } 100\% = \frac{7}{7} \; x \; 100\% = 100\%$$

b) Black Box Testing

System testing using black-box testing is a method of testing a system to discover any functions or features that may be less accurate and to test whether the system is running according to the desired features, thereby verifying whether the results obtained align with the established design. The results of testing using the black-box testing model.

c) UAT

Below in Table 4 are the results of testing using the UAT.

Table 4. User Acceptance Test (UAT)

Questions	Score	Percentage
P1	69	92%
P2	71	94,7%
…	…	…
P10	66	96%
TOTAL		92,94%

4 Conclusion

The implementation of the AHP method and the GMM, based on manual calculations in Excel, on the functioning system has successfully generated the oil insulation quality index values from multiple experts in transformers. The average user satisfaction level is 92.94%. The accuracy of the Confusion matrix results is 100%, which helps determine the oil insulation quality index in transformers. Suggestions for further research include adding a feature to import data from experts to calculate data from Excel to the application, which can be accomplished by creating a program to compute the health index of oil insulation conditions in transformers.

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