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Multi-criteria decision support system using AHP method to determine the weight of transformer paper insulation index

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Abstract - The transformer has evolved into an electrical device that operates based on the principle of electromagnetic induction without altering the frequency, capable of transferring electric energy from one or more electrical circuits to others by means of magnets. Insulation material is utilized as equipment to safeguard electrical components, where the resilience of each insulation plays a significant role in the functioning of the system. In addition to providing mechanical strength and distance, paper insulation functions as a dielectric medium. The quality of paper insulation deteriorates due to excessive heat generated from oil oxidation, leading to a degradation process known as depolymerization. In addressing this issue, a Decision Support System is required to aid in calculating the condition index of the paper insulation based on given parameters. The chosen method is the Analytic Hierarchy Process (AHP) utilizing multiple criteria. The outcome of applying this method is that the entire system operates as intended, and the calculation process yields appropriate results. Testing results, which involve a comparison between manual calculations and the Confusion Matrix system, exhibit a 100% accuracy rate. Additionally, user testing yields an average satisfaction level of 90.97%. In conclusion, this system adequately fulfils its intended purpose and significantly helps to determine the quality level of paper insulation in transformers.

Keywords: AHP, decision support system, multi criteria, transformer, transformer paper insulation

1 Introduction

Electrical energy is one of the main needs for the community after water. The increasing number of people who make the demand for electricity is increasing. So that electrical equipment manufacturers continue to increase, one of the electrical equipment that is widely used is the transformer [1]. The use of very simple transformers is one of the important reasons that alternating current is very widely used for the generation and distribution of electricity.

The material used to prevent short circuits is insulating material. Where the resistance of each insulation has an influence on the system that runs. If there is a high insulation resistance and a strong dielectric, then electrical insulation is said to be good [2]. The main insulation in transformers consists of oil, paper and some cellulose materials. One component of the transformer insulation system is paper insulation. In addition to providing mechanical strength and distance, paper insulation functions as a dielectric medium. The quality of paper insulation decreases due to excessive heat from oil

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oxidation. The decline that occurs is a depolymerization process. In this process, the paper insulation as a hydrocarbon chain will be disconnected and will reduce the tensile strength of the paper insulation itself [3].

Previous research related to transformer analysis was conducted by [4] the title "Analysis of Aging Rate of Paper Insulation Using Ester-Based Oil in Environmentally Friendly Transformers" explains that there is a material capable of extending the lifespan of paper insulation, which tends to deteriorate due to excessive heat. To prevent premature aging of the paper insulation, a method involving the use of Ester-based oil and measuring the Dissipation Factor (DP) in the paper is employed as an indicator of the remaining transformer lifespan.

The next research "Power Transformer Condition Monitoring with 2FAL Content and CO2/CO ratio - Fuzzy Logic Approach" by [5] The result of the research is to present a tool that can predict the condition of paper insulation in transformers using fuzzy logic. The tool used has a content value, namely 2-FAL and CO2 / CO ratio, which can get information related to paper conditions directly and this tool makes it easy to monitor the condition of paper insulation. Paper condition can also be determined using parameter values from a tool input.

Research related to decision support systems using AHP on "Decision Support System with AHP Method for Employee Soft Skill Competency Assessment" to assess employee abilities, especially in the field of soft skills. This assessment of soft skills has not been done much because companies generally only assess how work can be done to achieve a target or can be called hard skills. In this study, four criteria were applied to assess soft skills including communication skills, cooperation skills, honesty, and interpersonal skills. The results of the assessment of the priority of soft skill competencies needed are 48% Communication, 27% Cooperation, 16% Honesty, and 10% Interpersonal, so that it can prove that the AHP method can be used to assess employee soft skills in companies [6].

In the research results from a journal entitled "Application of the AHP Method to Determine the Quality of Finished Clothing in the Garment Industry", namely determining the quality of finished clothing. Quality in clothing is a major factor in producing quality standards. Assessment of the type of clothing depends on the type of material. Not only on quality but other details can be a concern, for example on the neatness of the stitches. So this research uses the AHP method to determine the criteria and alternative choices. From the results of this study, the consistency ratio is 0.045 which is less than 0.1 so it is said to be consistent. With the calculation of 76.60% Size criteria, 11.2% Stitching, and 13.2% Material, the quality of clothing is a more important quality [7]. Transformers are electrical devices that operate based on the principle of electromagnetic induction without changing the frequency and can transmit electrical energy through a magnetic connection from one or more electrical circuits to another electrical circuit [8].

Based on the results of research entitled "Decision Support System Based on the Analytical Hierarchy Process (AHP) Method in the Selection of Quality Coffee Beans" explains that one of the regions in Indonesia that produces the best coffee is the Bengkulu area. In selecting coffee criteria, they still use manual techniques, so that the selection of the best coffee beans is a limitation in Bengkulu Province. Using the AHP method can make it easier to determine the selection of quality coffee beans. The research results for the overall total alternative comparison are Kepahiang 0.285, South Bengkulu 0.266, North Bengkulu 0.210, Lebong 0.130, and Rejang Lebong 0.109 with each consistent CR value.

Based on several previous studies, it has not discussed the decision support system for transformers with AHP so that it shows that in calculating the paper insulation condition index, the

expert considers several criteria to determine the calculation of the index. So that with the AHP method to get the results of how the paper insulation on the transformer does not decrease. It is hoped that this decision support system can serve as a reference to improve the cause of the decline in paper insulation by entering more than two criteria or multi criteria in the application. After the process of inputting criteria with parameters that are already available, it is possible to calculate the paper condition index. After the calculation process is complete and getting the weighting results will produce a decision to determine the index obtained from paper insulation. The decision is taken from the ranking results through the multi-criteria AHP method.

2 Materials and methods

2.1 Data collection

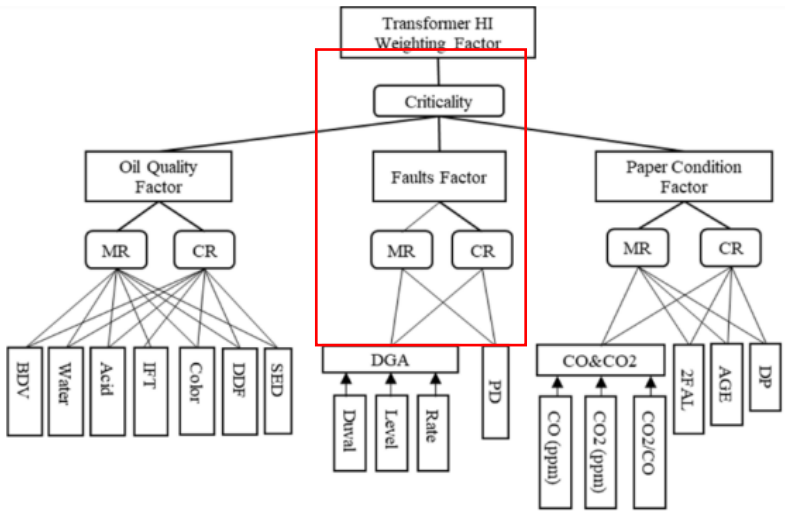

Fig 1. AHP Hierarchy for Transformer Rating Index Weighting Factors [9]

Based on Fig 1, the parameters obtained to determine the paper condition index consist of Carbon Monoxide (CO), Carbon Dioxide (CO2), 2furaldehide (2FAL), Age (AGE), and Degree of Polymerization (DP). Each parameter is compared with each other using a pairwise comparison matrix based on two criteria, namely Measurement Reliability (MR) and Criticality (CR). MR aims to measure the reliability of the results on each parameter, and CR is intended to measure the criticality of the parameter compared to others. There are 143 operating power transformer populations from the Indonesian power company PT PLN (Persero) UIT East Java and Bali. Most of the observed transformers use kraft paper insulation and the age of the transformers varies [10].

2.2 Data processing

Analytic Hierarchy Process (AHP) is a decision-making model that decomposes complex multi-factor or multi-criteria problems into a hierarchy. Complex problems can mean that the criteria of a problem are so many (multi criteria), the structure of the problem is not yet clear, the uncertainty of the opinion of the decision maker, the decision maker is more than one person and the inaccuracy of the available data. With hierarchy, complex problems can be decomposed into groups that form a hierarchy so that the problem becomes more structured and systematic [7]. With the parameters used are Carbon Monoxide (CO), Carbon Dioxide (CO2), 2furaldehide (2FAL), Age (AGE), and Degree of

Polymerization (DP) [5]. Each parameter is compared with each other using a pairwise comparison matrix based on two criteria, namely Measurement Reliability (MR) and Criticality (CR). Then, the results of the pairwise comparison are checked using consistency of comparison. Weighting factors are determined using AHP [9]. In the AHP method, the following steps are carried out:

2.2.1 Develop a hierarchy of the problem at hand

The problem to be solved and decomposed into its elements, namely criteria and alternatives. Then organized into a hierarchical structure as in Fig 2.

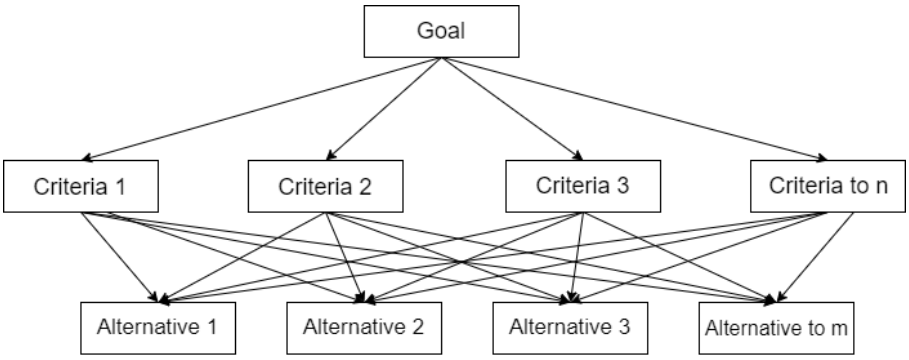

Fig 2. AHP Hierarchy Structure

2.2.2 Assessment of criteria and alternatives

Criteria and alternatives are assessed through pairwise comparisons. According to Saaty (1988), for various problems, a scale of 1 to 9 is the best in expressing opinions. The value and qualitative opinion definitions of Saaty's comparison scale can be seen at Table 1.

Table 1. Pairwise Comparison Rating Scale Source: [11]

Intensity of interest	Description
1	Both elements are equally important
3	One element is slightly more important than the other
5	One element is more important than the other
7	One element is clearly more absolutely essential than the other
9	One element is more absolutely important than the other
2,4,6,8	Values between two adjacent consideration values

2.2.3 Choosing Priorities

For each criterion and alternative, pairwise comparisons need to be made. The relative comparison values are then processed to determine the ranking of alternatives from all alternatives. Consideration of pairwise comparisons is synthesized to obtain overall priorities through the following stages:

1 Squaring the matrix of pairwise comparison results.
2 Calculate the sum of the values of each row then normalize the matrix.

2.2.4 Determining the logical consistency value

The calculation of logical consistency is done by following the steps below:

1 Multiplying each value in the first column with the relative priority of the first element, the value in the second column with the relative priority of the second element and so on..
2 Summing up the multiplication results per row.
3 The sum of each row is divided by the corresponding priority and the results are summed.
4 Sum the quotient with the number of elements, then the result is called λ max.

2.2.5 Determine the consistency index (CI) value

The formula (1) used is as follows:

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

Description:
n = Number of criteria

2.2.6 Determine the consistency ratio (CR)

The formula (2) used is as follows:

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

Description:
CR = Consistency Ratio
CI = Consistency Index
RI = Random Consistency Index

2.2.7 Checking the consistency of the hierarchy

If the calculation result of the consistency ratio value is more than 10%, it must be corrected or recalculated. But if the consistency ratio is less than or equal to 0.1, then the calculation value can be declared correct. The random index (RI) value can be seen in Table 2 [12].

Table 2. Pairwise Comparison Rating Scale

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
RC	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

2.3 System workflow

Flowchart diagram on Fig 3 explains a workflow or process in a system. So that you can analyze each process of the system

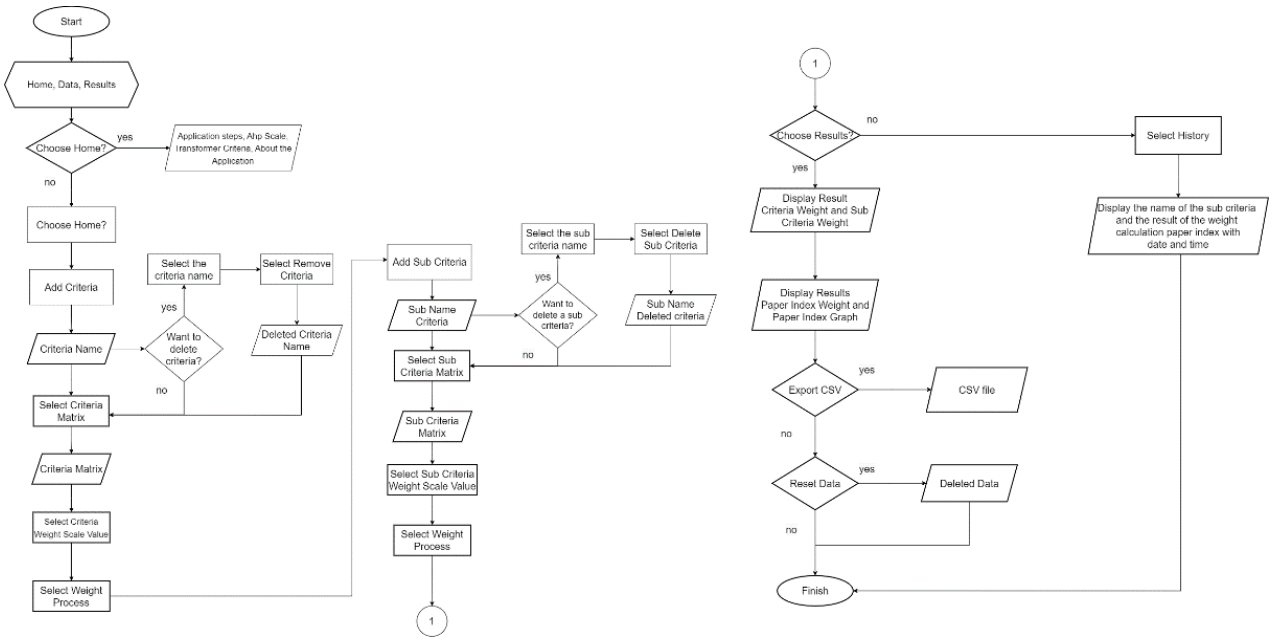

Fig 3. Information System Workflow

Based on Fig 3 there are Home, Data and Results menus on this system. The flow of the decision support system for determining the weighting factor for the multi-criteria transformer paper condition index using AHP is that when opening the system there are three menu options, the first is the home page, if the user wants to see the functions and steps for using the application. Second on the data page, the user can perform AHP calculations to get weight results by adding criteria data which can be more than two criteria. When the criteria data is stored, it can provide the weight value of the criteria through a comparison matrix. Then the user can add sub-criteria data whose calculations are the same as the calculation of criteria data. But when giving the weight value of the sub criteria, it displays a comparison matrix according to the amount of criteria data.

Third on the results page, users can see the results of the weight of the criteria and the weight of the sub criteria. In addition, it can see the results of the paper index weight on the transformer and visualization of the AHP results. Users can save data from the calculation of criteria, sub criteria and paper index weights in the form of csv files. If the user wants to delete the data, they can choose to reset the data, where the calculation data will be deleted and can input new data. After that the user can see the history page or calculation history by displaying the name of the sub criteria, the calculation results of the paper index weight and the calculation date.

2.4 Needs analysis

Requirements that have a relationship with the system are called functional requirements. The following Table 3 describes the functional requirements.

Table 3. Functional Requirements

No	Actor	User Needs
1	Admin	View parameter functions on paper insulation
2	Admin	Manage data on paper insulation criteria
3	Admin	Manage paper insulation sub criteria data
4	Admin	Observing the results of the weight calculation for criteria and sub-criteria.
5	Admin	View the results of the paper condition index weight and paper index weight chart

No	Actor	User Needs
6	Admin	Export data to csv
7	Expert	Expert can fill in criteria and sub criteria data
8	Expert	Expert can see the results of the calculation of the weight of criteria and sub criteria of paper conditions
9	Expert	Expert can see the result of paper condition index weight and paper index weight chart
10	Expert	Export data to csv

Then for non-functional needs is the limitation of the ability specification service on the system. Non-functional requirements are described in **Error! Reference source not found.** below:

Table 4. Non-Functional Requirements

No	Actor	User Needs
1	Usability	The system can be run via desktop.
2	Portability	This system can be used on devices such as laptops and computers.
3	Reliability	This system is reliable in determining the paper insulation condition index based on criteria and sub criteria.
4	Supportability	This system does not require internet, because it can be run on a desktop to use it.

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 to compare the results of calculations manually and on the system as follows:

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

2.5.2 User acceptance testing (UAT)

To calculate the results of this User Acceptance Testing (UAT) test using a Likert Scale with the following calculation formula:

$$P=\frac{J}{Y}X100\% \quad (4)$$

2.5.3 Blackbox testing

This test is to test the functional to be by taking a look at the execution results through test data and monitoring the application's functionality. Testing with this method to find errors or bugs includes:

1 Interface errors
2 Performance errors
3 Functionality errors that are not correct or user friendly

3 Results and discussion

The data processing technique in this study uses the Analytic Hierarchy Process (AHP) method. The following is a calculation using the AHP method:

3.1 Structuring the hierarchy of the problem at hand

The structuring can be seen in Fig 4 below:

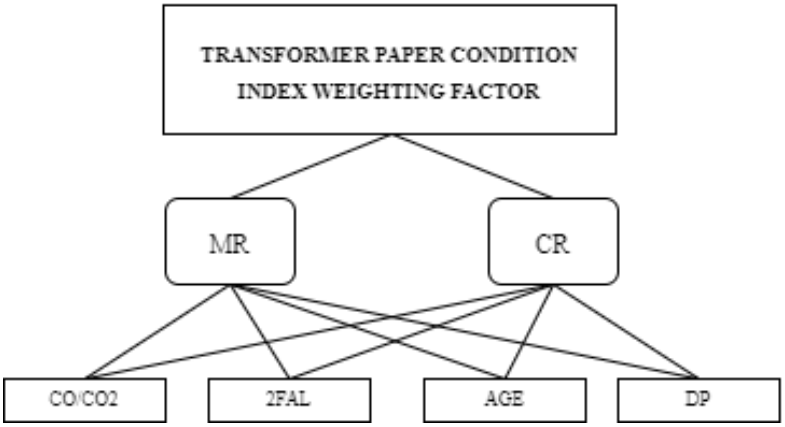

Fig 4. Transformer Paper Condition Index Weighting Factor

3.2 Pair comparison matrix

Making pairwise comparisons based on the value and definition of qualitative opinions from Saaty's comparison scale can be seen in **Error! Reference source not found.** below:

Table 5. Pair Comparison Matrix

Criteria	MR	CR
Measurement Reliability (MR)	1/1	1/4
Criticality (CR)	4/1	1/1

3.3 Calculating Priority Weight and Normalization

Summing up the values of each column in the matrix can be seen in **Error! Reference source not found.** below:

Table 6. Calculating Priority Weight and Normalization

Criteria	MR	CR
Measurement Reliability (MR)	1.00	0.25
Criticality (CR)	4.00	1.00
Total	5.00	1.25

After that, divide each value of the column by the total column concerned to obtain the normalization matrix and add up the values of each row. Then divide it by the number of elements to get the average value (Eigen Vector Value) or Weight Priority (WP) can be seen in **Error! Reference source not found.** below:

Table 7. Weight Priority

Criteria	MR	CR	Total	Wp
MR	0.20	0.20	0.40	0.2
CR	0.80	0.80	1.60	0.8

3.4 Calculating Consistency Ratio

Multiplying the matrix by Weight Priority (WP) can be seen Table 4 below:

Table 4. Multiplication Matrix with Weight Priority

Measurement Reliability (MR)	0.4
Criticality (CR)	1.6

Dividing the results of the above calculations by Weight Priority (WP) can be seen in Table 5 below:

Table 5. Division by Weight Priority

Measurement Reliability (MR)	0.5
Criticality (CR)	0.5

Calculating $\lambda maks$:

$$\lambda maks = \frac{0.5+0.5}{2} = 0.5 \quad (5)$$

Calculating Consistency Index (CI):

$$CI = \frac{(0.5-2)}{(2-1)} = -1{,}5 \quad (6)$$

Consistency Ratio (CR) can be seen in Table 6 below:

Table 6. Division by Weight Priority

n	1	2	3	4	5	6	7	8	9	10	11
RC	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

From the RC table obtained for N = 2, RI = 0.00; Consistency Ratio (CR) = -1.5/0.00 = 0.0 (<=0.1, **consistent**)

3.5 Calculating pairwise comparisons

With the same calculation method, the Consistency Ratio (CR) for pairwise comparisons between sub-criteria can be seen in Table 7 and Table 8 below:

Table 7. Consistency Ratio (CR) criteria Criticality (CR)

Sub Criteria	CO2/CO	2FAL	AGE	DP	WP	CR
CO&CO2	1.00	0.25	3.00	0.25	0.12713	0.059378
2FAL	4.00	1.00	6.00	0.50	0.344416	
AGE	0.33	0.17	1.00	0.20	0.063431	
DP	4.00	2.00	5.00	1.00	0.465023	

Consistency Ratio (CR) = **0.059** (<=0.1, **consistent)**

Table 8. Consistency Ratio (CR) criteria Measurement Reliability (MR)

Sub Criteria	CO2/CO	2FAL	AGE	DP	WP	CR
CO&CO2	1.00	4.00	0.20	3.00	0.226031	0.092138
2FAL	0.25	1.00	0.14	0.33	0.058582	
AGE	5.00	7.00	1.00	4.00	0.583491	
DP	0.33	3.00	0.25	1.00	0.131896	

Consistency Ratio (CR) = **0.092** (<=0.1, **consistent**)

3.6 Total Ranking or Decision Making

The total ranking results based on the comparison of the calculation of the multiplication of Weight Priority (WP) criteria and Weight Priority (WP) sub criteria can be seen in

Table **9** below:

Table 9. Total Ranking

	MR	CR	Evaluation Weight
Priority Weight	**0.2**	**0.8**	
CO&CO2	0.226031	0.12713	0.14691
2FAL	0.058582	0.344416	0.287249
AGE	0.583491	0.063431	0.167443
DP	0.131896	0.465023	0.398397

3.7 System calculation results

This Decision Support System uses the Analytic Hierarchy Process (AHP) method to determine the paper condition index on the transformer. The following are the results of the calculation of the AHP method on the system:

3.7.1 Creating a comparison matrix

Each criterion will be formed a comparison matrix as shown in Fig. **5** below:

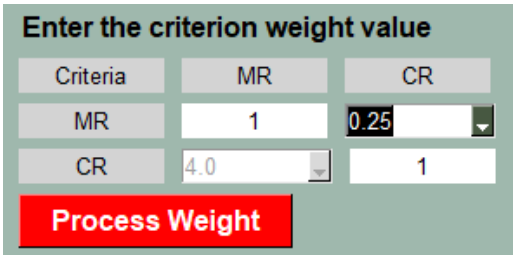

Fig. 5. Criteria Comparison Matrix

For each sub-criteria or parameter, a comparison matrix between criteria will be formed as shown in Fig. **6** below:

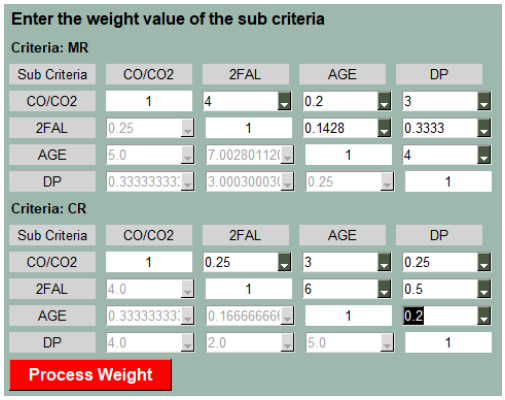

Fig. 6. Sub Criteria Comparison Matrix

3.7.2 Calculating priority weight

The criteria comparison matrix that has been formed will be normalized, then the normalization results are calculated to get the weight value (Weight Priority) as shown in Fig ***7*** below:

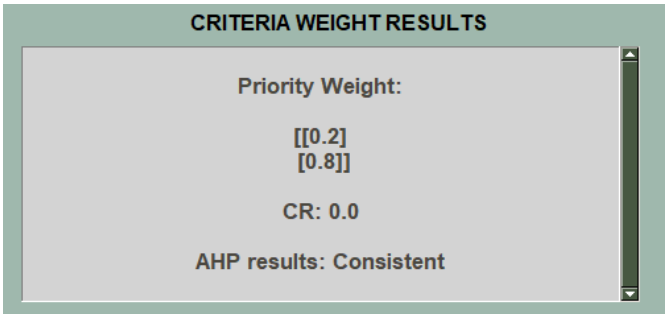

Fig 7. Criteria Priority Weight Result

In the comparison matrix of sub criteria or parameters that have been formed will be normalized based on the type of criteria, the normalization results are calculated to get the weight value (Weight Priority) can be seen in Fig 8 and Fig. **9** below:

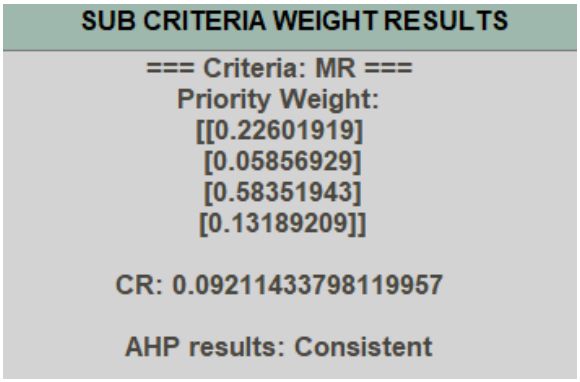

Fig 8. Result of Sub Criteria Priority Weight (MR)

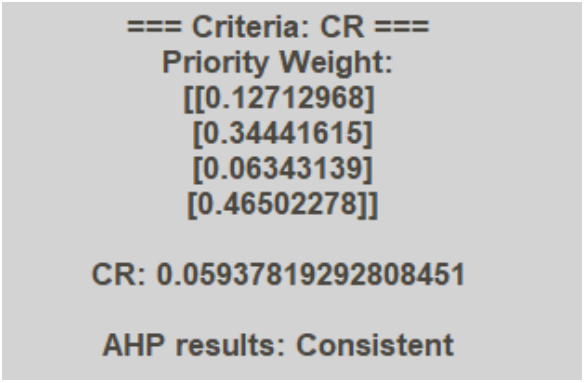

Fig. 9. Result of Sub Criteria Priority Weight (CR)

3.7.3 Calculating paper index weight or decision making

The decision-making calculation is based on the comparison of the calculation of the multiplication of wp criteria with wp sub criteria (parameters). Among the results of sub criteria (parameters) will produce different paper index weight values. By having a large or high weight value, the weight is considered critical or important compared to parameters with lower weight values. The computation's outcomes are displayed in Fig. **10** below:

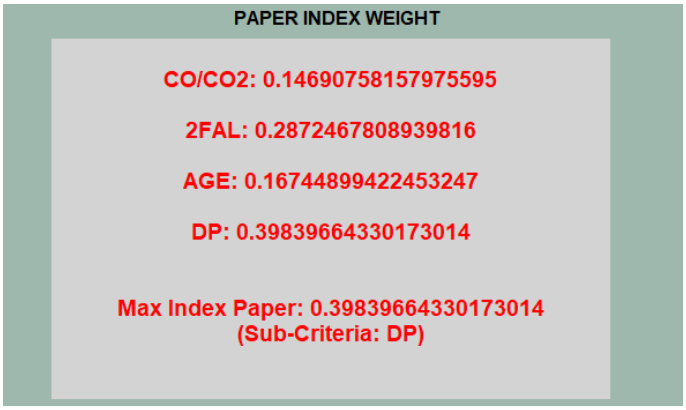

Fig. 10. Paper Index Weight Result

Following the acquisition of the paper index's weight value, the findings are displayed in the picture visualization, namely as a bar chart, as show in Fig. **11** below:

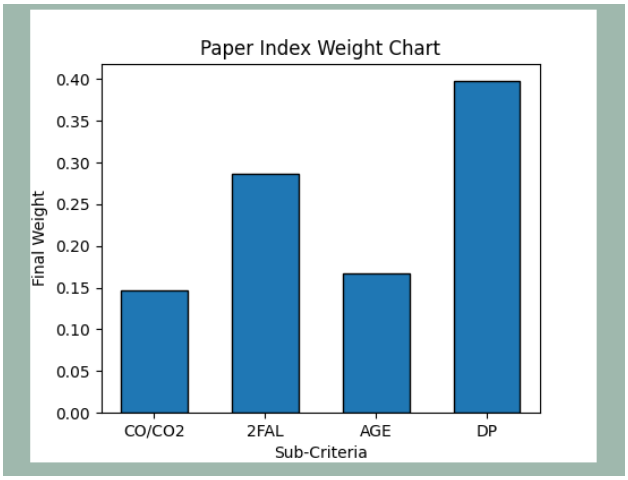

Fig. 11. Paper Index Weight Chart

3.8 Testing Results

Testing is done on the system and user side. For the system side, testing uses black box and the user side uses *User Acceptance Test* (UAT). While testing the accuracy of the AHP method using Confusion Matrix.

3.8.1 Method Testing

Testing methods using Confusion Matrix to compare the results of manual and system calculations. The following

Table 10 is the result of the comparison.

Table 10. System and Manual Ranking

Sub Criteria (Parameter)	Paper Index Weight		Results
	Manual	System	
CO/CO2	0.14691	0.14691	Appropriate
2FAL	0.287249	0.287249	Appropriate
AGE	0.167443	0.167443	Appropriate
DP	0.398397	0.398397	Appropriate

Based on the data in

Table 10, there are 4 predicted data that match the actual data or called TruePositive, and 0 predicted data that is not the same as the actual data or called FalseNegative. From these data, the accuracy can be calculated as follows:

$$Accuracy = \frac{TP+TN}{TP+TN+FP+FN} x100\% = \frac{4+0}{4+0+0+0} x100\% = 100\% \quad (7)$$

The accuracy results of the AHP calculation on the Decision Support System for Determining the Weighting Factor for the Multi Criteria Transformer Paper Condition Index Using AHP get a result of 100%.

3.8.2 Black Box Testing

In system testing using the Black Box Testing method which aims to see if the system is running in accordance with the design that has been made. Testing using Black Box Testing. All features of the system that have been made have run in accordance with the design that was determined at the beginning of the system design.

3.8.3 User Accetance Test (UAT)

The following in Table 11 is the result of testing using *User Acceptance Test* (UAT)

Table 11. User Acceptance Test (UAT)

Question	Score	Percentage
P1	70	93.3%
P2	64	85.3%
P3	70	93.3%
P4	71	94.6%
P5	69	92%
P6	69	92%
P7	64	85.3%
P8	69	92%
TOTAL		90.97%

4 Conclusion

This research gets the final result of an average satisfaction of 90.97%. These results can be concluded that the system can meet the needs and can help experts to determine the weight of the paper condition index on the transformer. The accuracy results by comparing the calculation results of the manual method with the system using the Confusion Matrix method on 4 sub-criteria data (parameters) get an accuracy result of 100%. Functional testing of the system found that all systems run according to their functions and calculations on the AHP method system run well. Suggestions for further research by adding features to import data from experts to calculate data from excel to the application and adding a program to determine the transformer's health index paper condition.

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