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Prioritizing SCADA Integration at Keypoints Using Fuzzy AHP and TOPSIS Methods: A Case Study in PLN UP2D Makassar

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ABSTRACT

PLN UP2D Makassar regulates the 20 kV electrical distribution network in South Sulawesi, Southeast Sulawesi, and West Sulawesi. PLN UP2D Makassar holds a management contract, which is SCADA integration. Based on the Network Database Book, in 2023, there were 128 keypoints (LBS and reclosers) that were not yet integrated with SCADA or not online with the Master SCADA. The current issue identified in making decisions on SCADA integration at keypoints in PLN UP2D Makassar is using the criteria of Keypoint Ratio Value per PLN UP3. The weakness of this method is that SCADA integration at keypoints does not consider its benefits and impacts: the improvement of SAIDI and ENS. This study aims to create guidelines for decision-making on SCADA integration at keypoints. This research involves 5 experts in PLN UP2D Makassar. A total of 6 criteria were established and processed using the Fuzzy AHP TOPSIS methods to rank the 128 keypoints that will be integrated with SCADA. The Fuzzy AHP TOPSIS calculation results have been validated with a consistency ratio of -0.008 (consistent) and sensitivity analysis (10% increase/decrease in criteria weight). This means that the 6 criteria can be used to rank alternative keypoints that will be integrated with SCADA.

Introduction

PT PLN (Persero) Unit Pelaksana Pengatur Distribusi (UP2D) or Distribution Control Center has a vital role in regulating the loading of a medium voltage electric power distribution network in work areas spread across South Sulawesi, Southeast Sulawesi, and West Sulawesi (Sulselrabar). Medium Voltage Networks generally have voltages of 20 kV (Bayu, Arif, & Nirwana, 2023). The supply of the 20 kV electric power distribution network is channeled through feeders sourced from Substations (GI) and Connecting Substations (GH). A total of 476 feeders are operated by UP2D Makassar to serve 10 PLN UP3 (Customer Service Implementation Units) in the area of Sulselrabar.

PLN UP2D Makassar in maintaining the reliability of the operation of the 20 kV power grid must meet the Key Performance Indicator (KPI) or management contract, both internally and externally. Internal system reliability is the ability of the network to circulate electrical energy continuously as it is generated. The indicator used in PLN's performance related to this phenomenon is Energy Not Served (ENS). ENS is the energy that is not delivered by the system to consumers during a certain period due to system capacity shortages or unexpected power outages (Joyokusumo et al., 2020). SAIDI is a measure of the duration (hours) of disruption experienced by the average customer in a year (Anteneh & Khan, 2019).

PLN UP2D Makassar integrates SCADA at keypoints to reduce ENS, suppress SAIDI, and increase the number of smart feeder implementations. PLN UP2D Makassar currently has integrated 414 Feeders, 506 GH, 1,119 keypoints consisting of LBS and recloser, and achieved 78.30% of SCADA integration. The breakdown of these data is shown in Table 1.

Table 1
Number of Assets Operated

NO	KEYPOINT	SCADA	NON SCADA	TOTAL	% SCADA
1	FEEDER	414	62	476	86,97%
2	GH	506	252	758	66,75%
3	LBS	797	202	999	79,78%
4	RECLOSER	322	49	371	86,79%
	TOTAL	**2039**	**565**	**2604**	**78,30%**

To improve the effectiveness of feeder operation on GI and GH and keypoint operation, such switch gears must be integrated with SCADA. Power grid devices will be monitored and controlled remotely by dispatchers via SCADA. Feeders, GH, LBS, and recloser are installed with Remote Terminal Units (RTUs) for tele signaling, tele indication, and tele control systems (Ashour, 2018). Communication media for sending and receiving data include radio, GPRS modems, and optical fiber. In the Distribution Control Center there is also a master station so where dispatchers can control it via computer. This can be seen in Figure 1.

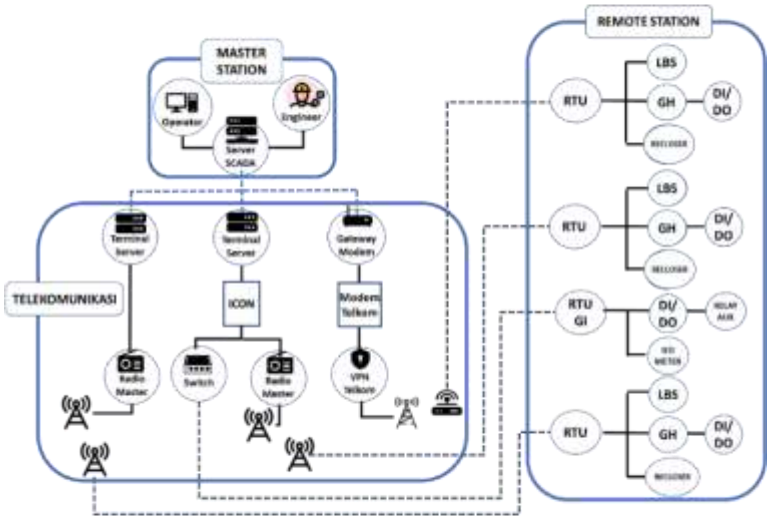

Fig 1. Topology of SCADA of PLN UP2D Makassar

A research gap found based on a literature review is that there was no previous study on decision-making regarding the integration of SCADA at keypoints in Sulselrabar. The criteria considered during SCADA integration at keypoints include SCADA integration costs, feeder loads (Amperes), trip times experienced by keypoints in 2023, load profiles served (premium, VIP, industrial, general customers), keypoints distance from service offices (km), and Energy Not Served (ENS) from keypoints (kWh).

Given the large number of keypoints installed, all of the criteria considered above require a precise method of making decisions on the integration of SCADA at those keypoints. The approach used in this study is Multi Criteria Decision Making (MCDM). MCDM is one of the most accurate methods of decision making and has been recognized as a revolution in operation research area (Taherdoost & Madanchian, 2023). MCDM assists researchers in evaluating, sorting, and selecting alternatives based on intersecting criteria according to the priorities of decision makers (Moradpour & Long, 2019).

Behzadian (in Sasmita et al., 2021) stated that the MCDM Method has been used as an object of active research and produced several papers and books since the 1960s based on knowledge concepts from many fields, such as behavioral decision theory, economics, mathematics, computer technology, software engineering and information systems. MCDM design is aimed at preferred alternatives, classifying alternatives from a small number of categories and ranking alternatives in the form of subjective order of preference.

Fuzzy sets are combined with AHP to form the Fuzzy AHP method (FAHP). FAHP covers the weaknesses contained in AHP. The use of FAHP is intended to help decision makers see the level of importance between criteria by using intervals instead of exact numbers. The results obtained in FAHP are excellent in representing the judgment of decision makers compared to AHP method. To process impressions in AHP, exact numbers are replaced with Fuzzy numbers which represent linguistic expressions of FAHP. This approach tolerates ambiguous judgments by assigning degrees of membership to an appropriate number to describe the extent to which that number is included in the expression. FAHP is a popular method for overcoming inaccuracies (Liu et al., 2020). This integrated process retains the advantages of AHP and is widely used in the automotive industry, logistics, manufacturing, transportation industry, pharmaceutical, supplier selection, sustainability management, and technology selection.

All criteria in this study will be compared in pairs (pair-wise comparison) and each weight is calculated using the FAHP method (Mustajib, Ciptomulyono, & Kurniati, 2021). The weight is then applied to rank the alternative keypoints integrated with SCADA using the Technique for Others Preference by Similarity to Ideal Solution (TOPSIS) method. This study will calculate the keypoints preference value that will be a priority for SCADA integration in PLN UP2D Makassar. The alternative is considered optimal if the value obtained is closer to Positive Ideal Solution (SIP) and simultaneously moves away from Negative Ideal Solution (SIN), and vice versa; the alternative becomes not a priority if it moves away from SIP and gets closer to SIN (Yang et al., 2022). The ranking results will be used as a basis for prioritizing keypoints integrated with SCADA.

Research Methods

This study uses quantitative methodology, which compares 1 (one) criterion with other criteria and determines the relationship between criteria by sorting the weight of the problem into parts that numbers can measure. The collected data becomes a reference in the prioritization process of SCADA integration at keypoints. Then, decision-making is carried out using the FAHP-TOPSIS methods. The result received is an alternate sequence of keypoints based on the highest preference value.

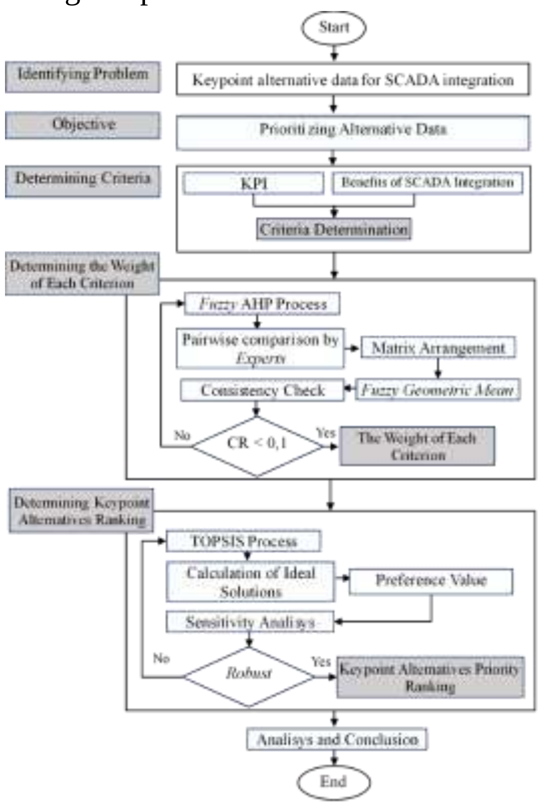

Fig. 2 Flowchart of Research Method

Identification and Modeling of Decision Systems

The problem discussed in this study is how to determine the priority of keypoint integration with SCADA on a 20 kV network system. The determination of keypoint integration with SCADA is based on several criteria obtained through consideration of KPIs and benefits of SCADA integration. Theories related to problems are studied in order to find the solutions to the cases. In addition, KPI considerations are carried out to impact the performance assessment of PLN UP2D Makassar significantly.

Data Collection

Data related to the research were collected from various sources, including questionnaires and data available at PLN UP2D Makassar.

1. Researcher compiles the questionnaire based on predefined criteria for SCADA integration at keypoints, which experts then fill in to compare each criterion.
2. Alternative non-SCADA keypoint data with criteria for SCADA integration cost, keypoint load, number of trips, load profile served, keypoint distance from unit office, and ENS were obtained from the PLN UP2D Makassar Network Databook and the meeting results about the SCADA Integration at Keypoints involving PLN UP2D Makassar and PLN UP3 of Sulselrabar.

FAHP-TOPSIS Analysis Phase

Data processing is a series of processes that convert raw data into information. The information obtained will be used as a benchmark in decision-making. The next step in the research is data analysis and processing using the FAHP-TOPSIS method. The data will be compared with related criteria to find the best solution to the problem, namely the priority of keypoint integration with SCADA.

Datasets

Making a list of data requirements aims to find which data is needed as a reference in determining keypoint priorities. These needs include the number of non-SCADA keypoints, criteria preparation, the keypoints information that match the criteria, and data related to and directly affected the SCADA integration at keypoints on the 20 kV PLN UP2D Makassar network system. The results of this data requirement list provide ease in determining the criteria involved with SCADA intergration at keypoints.

Furthermore, the obtained data is arranged and collected on Microsoft Excel tables in the form of a data model. This model facilitates the calculation process and implementation of the FAHP-TOPSIS methods.

Data Processing with FAHP Method

Weights are accurately determined for each indicator using the FAHP method. Determination of weights is carried out in several steps.

1. Weight measurement is carried out by experts who are considered to have the capability to assess objectively, in this case Assistant Manager of Planning (AMN REN), Assistant Manager of Distribution System Operations (AMN OPSISDIS), Assistant Manager of Operations Facility (AMN FASOP), Team Leader of Operation and Maintenance Evaluation Planning (TL REN EVALOPHAR), and Team Leader of

SCADA Planning (TL Ren SCADA) PLN UP2D Makassar. The experts will fill out a questionnaire, make a pairwise comparison, and give priority to the criteria.

2. Determine the matrix based on the results of paired comparisons made by converting numerical values to the TFN scale (defuzzification). It aims to get the average score of each criterion. Furthermore, using the geometric mean method, the weight of each criterion is calculated based on the average results of the experts' assessments.
3. Create a normalized matrix for more accurate results. The average value is also calculated at this stage.
4. The average value of the normalized matrix results in the weight of the criterion. The weight must be CR < 0.1. If the CR value > 0.1, the pairwise comparison assessment will be re-done by the experts. This is a reference that will be used in the TOPSIS method for determining the weight of decision-making calculations.

Data Processing with TOPSIS Method

After obtaining the weight value of each criterion from the AHP method, the next step is prioritization by sorting data using the TOPSIS method. The process of sorting data with the TOPSIS method is carried out as follows.

1. Determine the weight on each criterion through a decision matrix. This weight is obtained from the weight of the previous value determined by the AHP method.
2. The next stage is to calculate and prepare a normalized matrix by comparing the initial value of the criterion with repeated summation of the initial value.
3. Create a weighted normalized matrix by multiplying the normalized matrix and the weighted result of the FAHP method.
4. Specify SIP and SIN. SIP (Positive Ideal Solution) is a criterion value that if the property of the maximum value, the more ideal the solution. While SIN (Negative Ideal Solution) is a criterion value that if the more minimal the size, the more ideal the solution.
5. Specify preference value of each alternative. The alternative keypoint preference value is the value with the highest SIP and the lowest SIN.
6. Based on this preference value, the priority ranking of alternative keypoints to be integrated into SCADA can be arranged.

Sensitivity Analysis

Sensitivity analysis is critical in the MCDM process to ensure the robustness of the final decision. The sensitivity level is analyzed by changing the weights of the dominant criteria and reordering all alternatives using the TOPSIS method. It is used to identify how changes in weights given to each criterion will affect the final ranking of alternatives. In this study, the weight of the largest criterion was reduced by 10%. In contrast, the other criteria were increased proportionally. The weight of the largest criterion then was increased by 10%, while other criteria were lowered proportionally.

Results and Discussion

Determining the average element of a paired comparison matrix

The average element of the pairwise comparison matrix for each criterion is determined based on the matrix values obtained from the previous step. This element is calculated using the geometric mean method. For example, to determine the average element value on the ENS criterion (K1) and Keypoint Load criterion (K2). The TFN scale for comparison of K1-K2 criteria based on the results of the expert assessment questionnaire is as follows.

Table 2.
Expert Assessment Results for Comparison of K1 and K2 Criteria

Expert	*K1 or K2?*	*Numeric Scale*	TFN Scale		
			l	*m*	*u*
First	K2	7	1/4	2/7	1/3
Second	K2	7	1/4	2/7	1/3
Third	K1	7	3	3 1/2	4
Fourth	K1	7	3	3 1/2	4
Fifth	K1	9	4	4 1/2	4 1/2

For geometric mean value l

$$GM_1 = \left(\prod_{j=1}^{5} P_{1j}\right)^{\frac{1}{5}} = \left(\frac{1}{4}\ x\ \frac{1}{4}\ x\ 3\ x\ 3\ x\ 4\right)^{\frac{1}{5}}$$
$$= 1{,}1761$$

For geometric mean value m

$$\mathrm{GM}_1 = \left(\prod_{\mathrm{j}=1}^{5} \mathrm{P}_{1\mathrm{j}}\right)^{\frac{1}{5}} = \left(\frac{2}{7}\ \mathrm{x}\frac{2}{7}\ \mathrm{x}\frac{7}{2}\ \mathrm{x}\ \frac{7}{2}\ \mathrm{x}\frac{9}{2}\right)^{\frac{1}{5}}$$
$$= 1{,}3510$$

For geometric mean value u

$$GM_1 = \left(\prod_{j=1}^{5} P_{1j}\right)^{\frac{1}{5}} = \left(\frac{1}{3}\ x\frac{1}{3}\ x\ 4\ x\ 4\ x\frac{9}{2}\right)^{\frac{1}{5}}$$
$$= 1{,}5157$$

In the same way obtained the average value of the pairwise comparison matrix for each criterion.

Forming the A Matrix

A Matrix is obtained from the defuzzification process of geometric mean method as in the step above. The process of defuzzification into crisp numbers using Equation below.

Let's take for example the average value on the ENS (K1) criterion with the Keypoint Load criterion (K2) obtained from the geometric mean. The average value is (1,1761; 1,3510; 1,5157), or value l = 1,1761, m = 1,3510, and u = 1,5157.

$$P(\widetilde{M}) = \frac{(l+4m+u)}{6} = \frac{(1{,}1761+4(1{,}3510)+ 1{,}5157)}{6}$$
$$= 1{,}3493$$

This *crisp* number will form the A matrix.

$$\begin{vmatrix} 1{,}0000 & 1{,}3493 & 0{,}6821 & 1{,}0137 & 0{,}7022 & 0{,}9749 \end{vmatrix}$$

$$\boldsymbol{A} = \begin{vmatrix} 0{,}7451 & 1{,}0000 & 1{,}2267 & 0{,}6152 & 0{,}6208 & 1{,}2613 \\ 1{,}2341 & 0{,}8176 & 1{,}0000 & 0{,}7436 & 1{,}2864 & 1{,}2864 \\ 0{,}9936 & 1{,}5022 & 1{,}3465 & 1{,}0000 & 1{,}3211 & 1{,}3402 \\ 1{,}1000 & 1{,}3583 & 0{,}7805 & 0{,}6958 & 1{,}0000 & 1{,}2883 \\ 1{,}0354 & 0{,}7297 & 0{,}7805 & 0{,}6852 & 0{,}7816 & 1{,}0000 \end{vmatrix}$$

Forming the W Matrix

After forming the A matrix, the next step is forming the W matrix (normalized matrix) as the result of dividing each element of the A matrix by summation of its column. For example, to get the value of element w_{11}

$$w_{11} = \frac{a_{11}}{\sum_{i=1}^{n} a_{i1}} = \frac{1}{1+0{,}7451+1{,}2341+0{,}9936+1{,}1000+ 1{,}0354}$$
$$= 0{,}1637$$

By using the formula, the W matrix is obtained as follows.

$$\boldsymbol{W} = \begin{vmatrix} 0{,}1637 & 0{,}1997 & 0{,}1173 & 0{,}2133 & 0{,}1229 & 0{,}1363 \\ 0{,}1220 & 0{,}1480 & 0{,}2109 & 0{,}1294 & 0{,}1087 & 0{,}1764 \\ 0{,}2020 & 0{,}1210 & 0{,}1719 & 0{,}1564 & 0{,}2252 & 0{,}1799 \\ 0{,}1627 & 0{,}2223 & 0{,}2315 & 0{,}2104 & 0{,}2313 & 0{,}1874 \\ 0{,}1801 & 0{,}2010 & 0{,}1342 & 0{,}1464 & 0{,}1751 & 0{,}1802 \\ 0{,}1695 & 0{,}1080 & 0{,}1342 & 0{,}1441 & 0{,}1368 & 0{,}1398 \end{vmatrix}$$

Forming the AR Matrix

The AR matrix (weight matrix) is obtained by summing every element in each row then dividing it by the number of criteria. The element of the matrix is a weight of each criterion. For example, to determine the ar_{11} element

$$ar_{11} = \frac{\sum_{i=1}^{n} w_{1i}}{n}$$
$$= \frac{0{,}1637+0{,}1997+0{,}1173+0{,}2133+0{,}1229+0{,}1363}{6}$$
$$= 0{,}1589$$

Thus, the AR matrix is obtained as follows.

$$\boldsymbol{AR} = \begin{vmatrix} 0{,}1589 \\ 0{,}1492 \\ 0{,}1761 \\ 0{,}2076 \\ 0{,}1695 \\ 0{,}1388 \end{vmatrix}$$

Forming the B Matrix

To get the Maximum Eigen Value (λ_{max}), it is necessary to form the B matrix first. The B Matrix is obtained by multiplying each element of the A matrix and the AR matrix. For example, element of b_{11} is obtained using the formula $b_{11} = a_{11} \cdot ar_{11}$ = (1,0000) · (0,1589) = 0,1589 dan $b_{21} = a_{21} \cdot ar_{11}$ = (0,7451) · (0,1589) = 0,1184. Thus, the B matrix b is formed.

$$\begin{vmatrix} 0{,}1589 & 0{,}2013 & 0{,}1201 & 0{,}2104 & 0{,}1190 & 0{,}1353 \end{vmatrix}$$

$$B = \begin{vmatrix} 0{,}1184 & 0{,}1492 & 0{,}2160 & 0{,}1277 & 0{,}1052 & 0{,}1750 \\ 0{,}1961 & 0{,}1220 & 0{,}1761 & 0{,}1544 & 0{,}2180 & 0{,}1785 \\ 0{,}1578 & 0{,}2242 & 0{,}2371 & 0{,}2076 & 0{,}2239 & 0{,}1860 \\ 0{,}1748 & 0{,}2027 & 0{,}1374 & 0{,}1444 & 0{,}1695 & 0{,}1787 \\ 0{,}1645 & 0{,}1089 & 0{,}1374 & 0{,}1422 & 0{,}1325 & 0{,}1388 \end{vmatrix}$$

Forming the C and C/AR Matrix

The C matrix is formed by summing the elements of each row of the B matrix, while the C/AR matrix is formed by dividing each element of the C Matrix by the element of the AR matrix.

$c_{11} = \sum_{i=1}^{n} b_{1i}$ = 0,1589 + 0,2013 + 0,1201 + 0,2104 + 0,1190 +0,1353 = 0,9450

The C Matrix

$$C = \begin{vmatrix} 0{,}9450 \\ 0{,}8915 \\ 1{,}0450 \\ 1{,}2366 \\ 1{,}0076 \\ 0{,}8243 \end{vmatrix}$$

The C/AR Matrix

$$C/AR = \begin{vmatrix} 5{,}9487 \\ 5{,}9743 \\ 5{,}9348 \\ 5{,}9567 \\ 5{,}9449 \\ 5{,}9406 \end{vmatrix}$$

Obtaining Eigen Maximum Value (λ_{max})

Eigen Maximum Value is obtained using the formula

$$\lambda_{max} = \frac{\sum_{i=1}^{n} \frac{c_{i1}}{ar_{i1}}}{n} = \frac{5{,}9487+5{,}9743+,5{,}9348+5{,}9567+,5{,}9449+5{,}9406}{6} = \frac{35{,}699}{6} = 5{,}9500$$

Obtaining the value of CI and CR

The CI value is calculated using the formula

$$CI = \frac{\lambda_{max}-n}{n-1} = \frac{5{,}9500-6}{6-1} = \frac{-0{,}05}{5} = -0{,}0100$$

The CR value is obtained using the formula below, while the IR value of the 6-ordo matrix is 1,25.

$$CR = \frac{CI}{IR} = \frac{-0{,}01}{1{,}25} = -0{,}0080$$

As a result, the value of CR ≤ 0.1. Thus, the questionnaire assessing the level of importance of each criterion by the experts was declared consistent and acceptable.

Calculating Fuzzy Synthesis Value

In calculating the Fuzzy synthesis value, first determine the value of the geometric mean (GM) sum on a pairwise comparison matrix using the equation below. For example, suppose to get the sum value l, m, u, on the ENS criterion (K1).

$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j , \sum_{j=1}^{m} m_j , \sum_{j=1}^{m} u_j\right)$

$\sum_{j=1}^{m} l_j = 1 + 1{,}1761 + 0{,}6444 + 0{,}8769 + 0{,}7230 + 0{,}8219 = 5{,}2422$

$\sum_{j=1}^{m} m_j = 1 + 1{,}3510 + 0{,}6444 + 1{,}0073 + 0{,}6310 + 0{,}9696 = 5{,}6033$

$\sum_{j=1}^{m} u_j = 1 + 1{,}5157 + 0{,}8706 + 1{,}1761 + 0{,}9666 + 1{,}1487 = 6{,}6776$

The calculation of the sum of l, m, u on each criterion is presented in Table 3.

Table 3
Summation of rows of each criterion

Criterion	GM Summation		
	l	***m***	***u***
ENS	5,2422	5,6033	6,6776
Keypoint Load	4,9751	5,4221	6,1504
Load Profile Served	5,8925	6,3043	7,0995
SCADA Integration Cost	6,7758	7,4508	8,4428
Keypoint distance from unit office	5,9239	5,9959	7,4298
Number of Disturbances/Trips	4,5540	4,9560	5,6960

After calculating the sum of GM on each criterion, the value of the sum of the columns in the pairwise comparison matrix is determined. The sum of the columns on the matrix is calculated using Equation 2.10 to get the totals of l, m, and you. The results can be seen in Table 4.

$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i , \sum_{i=1}^{n} m_i , \sum_{i=1}^{n} u_i\right)$

$\sum_{i=1}^{n} l_i = 5{,}2422 + 4{,}9751 + 5{,}8925 + 6{,}7758 + 5{,}9239 + 4{,}5540 = 33{,}3634$

$\sum_{i=1}^{n} m_i = 5{,}6033 + 5{,}4221 + 6{,}3043 + 7{,}4508 + 5{,}9959 + 4{,}9560 = 35{,}7323$

$\sum_{i=1}^{n} u_i = 6{,}6776 + 6{,}1504 + 7{,}0995 + 8{,}4428 + 7{,}4298 + 5{,}6960 = 41{,}4962$

Table 4
Summation of Columns of Each Criterion

Column Summation	***l***	***m***	***u***
	33,3634	35,7323	41,4962

The sum of the columns of each criterion is then calculated as the inverse value using the equation below. The inverse of column summation is seen in Table 5.

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}$$

Table 5

Inverse of column summation of each criterion

Inverse of Column Summation	*l*	*m*	*u*
	0,0241	0,0280	0,0300

After the inverse value of column addition is known, it then calculates the Fuzzy synthesis value for each criterion obtained from multiplying the result of summing the rows of each criterion by the column sum inverse as in equation below.

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \ x \left[\sum_{i=1}^{n} \ \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$$

S_1 = (5,2422; 5,6033; 6,6776) × (0,0241; 0,0280; 0,0300)
= (0,1263; 0,1568; 0,2001)
S_2 = (4,9751; 5,4221; 6,1504) × (0,0241; 0,0280; 0,0300)
= (0,1199; 0,1517; 0,1843)
S_3 = (5,8925; 6,3043; 7,0995) × (0,0241; 0,0280; 0,0300)
= (0,1420; 0,1764; 0,2128)
S_4 = (6,7758; 7,4508; 8,4428) × (0,0241; 0,0280; 0,0300)
= (0,1633; 0,2085; 0,2531)
S_5 = (5,9239; 5,9959; 7,4298) × (0,0241; 0,0280; 0,0300)
= (0,1428; 0,1678; 0,2227)
S_6 = (4,5540; 4,9560; 5,6960) × (0,0241; 0,0280; 0,0300)
= (0,1097; 0,1387; 0,1707)

With:

S_1: Synthesis value Fuzzy ENS criterion
S_2: Synthesis value Fuzzy Keypoint Load criterion
S_3: Synthesis value Fuzzy Load Profile Served criterion
S_4: Synthesis value Fuzzy SCADA Integration Cost criterion
S_5: Synthesis value Fuzzy Keypoint Distance from Unit Office criterion
S_6: Synthesis value Fuzzy Number of Trips criterion

The results of these calculations can be separated between Fuzzy numbers l, m, and u. So that the Fuzzy synthesis values for each criterion can be seen in Table 6.

Table 6
Fuzzy Synthesis Value

Si Value	*l*	*m*	*u*
S1	0,1263	0,1568	0,2001
S2	0,1199	0,1517	0,1843
S3	0,1420	0,1764	0,2128
S4	0,1633	0,2085	0,2531
S5	0,1428	0,1678	0,2227
S6	0,1097	0,1387	0,1707

Specifying Vector Values

Vector value calculation using Equation

$$V\,(M_2 \geq M_1) = \begin{cases} 1 & for\; m_2 \geq m_1 \\ 0 & for\; l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & for\; the\; other\; conditions \end{cases}$$

For example, the vector value of the comparison of M_1 and M_2 can be found by calculating V ($M_1 \geq M_2$) and V ($M_2 \geq M_1$). Based on Table 6 it is known that M_1 has a value of l_1 = 0.1263, m_1 = 0.1568 and u_1 = 0.2001. While M_2 has a value of l_2 = 0.1199; m_2 = 0.1517 and u_2 = 0.1843. So, the value for V ($M_1 \geq M_2$) is 1 because it meets the requirements $m_1 \geq m_2$. For V ($M_2 \geq M_1$) does not meet the conditions of $m_2 \geq m_1$ and $l_1 \geq u_2$ so it is calculated by using the formula in the third condition, namely (l_1- u_2) / ((m_2- u_2) - (m_1-l_1)) = (0.1263-0.1843)/ ((0.1517-0.1843) - (0.1568-0.1263)) = 0.9196. The vectors values of each criterion can be seen in Table 7.

Table 7
Vector Value of Each Criterion

V ($M_2 \geq M_1$)	S1	S2	S3	S4	S5	S6
S1	1,0000	1,0000	0,7477	0,4162	0,8393	1,0000
S2	0,9196	1,0000	0,6317	0,2706	0,7214	1,0000
S3	1,0000	1,0000	1,0000	0,6068	1,0000	1,0000
S4	1,0000	1,0000	1,0000	1,0000	1,0000	1,0000
S5	1,0000	1,0000	0,9034	0,5933	1,0000	1,0000
S6	0,7102	0,7958	0,4323	0,0963	0,4901	1,0000

Determining the Ordinate Value

The ordinate values are determined based on the equation below and are presented in Table 8.

d' (Ai) = min V (M ≥ Mi)

For example, in Table 8 the results are obtained

V (S1 ≥ S2) = 1,0000;

V (S1 ≥ S3) = 0,7477;

V (S1 ≥ S4) = 0,4162;

V (S1 ≥ S5) = 0,8393; dan

V (S1 ≥ S6) = 1,0000.

Thus, d'(S1) = min (1,0000; 1,0000; 0,7477; 0,4162; 0,8393; 1,0000) = 0,4612.

Table 8
Ordinate Value of Each Criterion

	Ordinate Value
S1	0,4162
S2	0,2706
S3	0,6068
S4	1,0000
S5	0,5933
S6	0,0963

Furthermore, based on the table above, the value for vector weight is calculated using equation as follows.

W' = (d' (A1), d' (A2), …, d' (An)) T

W' = (0,4162; 0,2706; 0,6068; 1,0000; 0,5933; 0,0963) T

Normalization of vector weight values

Normalization of vector weight values is obtained using the equation below. For example, the normalized vector weight value for the ENS criterion (K1) is.

$W = (d\ (A_1),\ d\ (A_2),\ \ldots,\ d\ (A_n))\ ^T$

$$= \frac{d'(S_1)}{\text{total of } d'(S_i)} = \frac{0{,}4162}{2{,}9832} = 0{,}2587$$

Furthermore, the weight of each criterion can be seen in Table 9.

Table 9
Criterion Weight

Criterion	Weight
ENS	0,1395
Keypoint Load	0,0907
Load Profile Served	0,2034
SCADA Integration Cost	0,3352
Keypoint distance from unit office	0,1989
Number of Disturbances/Trips	0,0323

Calculation with TOPSIS Method

The TOPSIS method is useful for solving the decision-making problems practically. This is because the concept is simple and easy to understand, computationally efficient and able to measure the performance of decision alternatives in simple mathematical form. In this study, the TOPSIS method was used to determine the priority of keypoint integration with SCADA. Due to the large number of alternative keypoint data, this subchapter only displays 10 (ten) alternatives.

Table 10
Alternative Keypoints

No	Keypoint	Cost (Rp)	Load (A)	Event (time)	Profile	Distance (km)	ENS (kwh)
1	SECT_BULETE	10.000.000	15	2	Common	18	833
2	SECT_P1	9.500.000	130	0	Common	2	0
3	SECT_PARANG LABUA	9.000.000	60	3	Common	7	284
4	SECT_SMA 5	9.000.000	0	0	Common	4	0
5	SECT_TUWUNG	8.800.000	20	65	Common	6	148.368
6	SECT_ULU TEDONG	10.000.000	60	2	Common	4	561
7	REC_KASAMBI	9.200.000	3	0	Common	3	0
8	REC_KOMPLEK	9.200.000	3	0	Common	2	0
…	…	…	…	…	…	…	…
127	SECT_MABAR	11.000.000	0	0	Common	1	0
128	SECT_SULEWATANG	10.500.000	0	0	Common	7	0

Decision Matrix

Data collected through the PLN UP2D Makassar Network Data Book is the value of each keypoint alternative for each criterion. These values are then presented in the form of a decision matrix.

$x =$

0,8	15,0	2,0	10,0	18,0	2,0
0,0	130,0	2,0	9,5	1,5	0,0
0,3	60,0	2,0	9,0	7,1	3,0
0,0	0,0	2,0	9,0	4,0	0,0
148,4	20,0	2,0	8,8	6,0	65,0
0,6	60,0	2,0	10,0	4,1	2,0
0,0	3,0	2,0	9,2	3,0	0,0
0,0	3,0	2,0	9,2	2,0	0,0
...	...	...	...	...	...
0,0	0,0	2,0	11,0	1,0	0,0
0,0	0,0	2,0	10,5	7,0	0,0

Normalized Decision Matrix

The decision matrix is then normalized using by dividing the value of each alternative by the root of the square of the number of all alternatives for each criterion to obtain the following results.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$$

$r =$

0,0010	0,0327	0,0683	0,0657	0,1122	0,0066
0,0000	0,2838	0,0683	0,0624	0,0094	0,0000
0,0003	0,1310	0,0683	0,0591	0,0443	0,0099
0,0000	0,0000	0,0683	0,0591	0,0249	0,0000
0,1826	0,0437	0,0683	0,0578	0,0374	0,2142
0,0007	0,1310	0,0683	0,0657	0,0256	0,0066
0,0000	0,0000	0,0683	0,0604	0,0187	0,0000
0,0000	0,0065	0,0683	0,0604	0,0125	0,0000
...	...	...	...	...	...
0,0000	0,0000	0,0062	0,0000	0,0000	0,0683
0,0000	0,0000	0,0436	0,0000	0,0000	0,0683

Weighted Normalized Decision Matrix

The weighted normalized decision matrix is formed using the equation below. The weights are the results of calculations from the Fuzzy AHP method. For example, to get the value of the first alternative keypoint against the ENS criterion (K1) is

$$v_{11} = r_{11} \times w_1 = 0{,}0010 \times 0{,}1395 = 0{,}0001$$

A weighted normalized decision matrix is obtained as follows

$v =$

0,0001	0,0030	0,0139	0,0220	0,0223	0,0002
0,0000	0,0257	0,0139	0,0209	0,0019	0,0000
0,0000	0,0119	0,0139	0,0198	0,0088	0,0003
0,0000	0,0000	0,0139	0,0198	0,0050	0,0000
0,0255	0,0040	0,0139	0,0193	0,0074	0,0069
0,0001	0,0119	0,0139	0,0220	0,0051	0,0002
0,0000	0,0006	0,0139	0,0202	0,0037	0,0000
0,0000	0,0006	0,0139	0,0202	0,0025	0,0000
...	...	...	...	...	...
0,0000	0,0000	0,0139	0,0242	0,0012	0,0000
0,0000	0,0000	0,0139	0,0231	0,0087	0,0000

Positive Ideal Solution and Negative Ideal Solution

The Positive Ideal Solution (A+) of the criterion is the maximum value of the weighted normalized decision matrix in each column and the Negative Ideal Solution (A−) is taken from the weighted normalized decision matrix minimum value of each column. A+ and A- for each criterion can be seen in Table 11.

Table 11
Positive and Negative Ideal Solutions

	K1	K2	K3	K4	K5	K6
	ENS	Keypoint Load	Load Profile	Cost	Distance	Number of Trips
Positive Ideal Solution	0,0949	0,0277	0,0278	0,0193	0,0657	0,0130
Negative Ideal Solution	0,0000	0,0000	0,0139	0,1011	0,0001	0,0000

Alternative Distance from Positive Ideal Solution and Negative Ideal Solution

The alternative distance from Positive Ideal Solution (D+) and Negative Ideal Solution (D−) are obtained using equations below. For example, to get an alternative distance from the first keypoint.

$$D_i^+ = \sqrt{\sum_{j=1}^{m}\left(v_{ij}^+ - v_{ij}\right)^2}$$

$$= \sqrt{\begin{matrix}(0{,}0949-0{,}0001)^2+(0{,}0277-0{,}0030)^2+(0{,}0278-0{,}0139)^2\\+(0{,}0193-0{,}0220)^2+(0{,}0657-0{,}0223)^2+(0{,}0130-0{,}0002)^2\end{matrix}} = 0{,}1088$$

$$D_i^- = \sqrt{\sum_{j=1}^{m}\left(v_{ij} - v_{ij}^-\right)^2}$$

$$= \sqrt{\begin{matrix}(0{,}0001-0)^2+(0{,}0030-0)^2+(0{,}0139-0{,}0139)^2\\+(0{,}0220-0{,}1011)^2+(0{,}0223-0{,}0001)^2+(0{,}0002-0)^2\end{matrix}} = 0{,}0822$$

Alternative distances from the Positive Ideal Solution and Negative Ideal Solution for each keypoint alternative can be seen in Table 12.

Table 12
Alternative Distance from the Positive and Negative Ideal Solutions

Keypoint	D+	D-
SECT_BULETE	0,1088	0,0822
SECT_P1	0,1160	0,0842
SECT_PARANG LABUA	0,1133	0,0826
SECT_SMA 5	0,1176	0,0814
SECT_TUWUNG	0,0949	0,0863
SECT_ULU TEDONG	0,1152	0,0801
REC_KASAMBI	0,1181	0,0809
REC_KOMPLEK	0,1188	0,0809
…	…	…
SECT_MABAR	0,1197	0,0769
SECT_SULEWATANG	0,1158	0,0785

Proximity to Ideal Solutions

Calculating the proximity of each alternative to the positive ideal solution is by using the equation below. For example, to get the proximity value of the first alternative to the ideal solution (V_1) is

$$V_1 = \frac{D_1^-}{D_1^- + D_1^+} = \frac{0{,}0822}{0{,}0822 + 0{,}1088} = 0{,}4304$$

Table 13
Proximity to Ideal Solutions

Keypoint	V_i
SECT_BULETE	0,4304
SECT_P1	0,4207
SECT_PARANG LABUA	0,4216
SECT_SMA 5	0,4092
SECT_TUWUNG	0,4762
SECT_ULU TEDONG	0,4102
REC_KASAMBI	0,4066
REC_KOMPLEK	0,4051
…	…
SECT_MABAR	0,3912
SECT_SULEWATANG	0,4039

Keypoint Alternative Priority Order

Alternative priorities are ordered from the keypoint that has the largest preference value to the the smallest. Table 14 displays the top and bottom 10 (ten) keypoint alternative priorities.

Table 14
Keypoint Alternative Priority Order

Keypoint	Value	Priority
SECT_TAIPA	0,6606	1
SECT_CEMPA WELADO	0,5951	2
REC_LEMBU	0,5753	3
REC_LASOLO	0,5081	4
REC_BUPATI KONSEL	0,5070	5
REC_BIMA MAROA	0,5003	6
REC_ROMPU-ROMPU	0,4963	7
SECT_PANJUTANA	0,4947	8
REC_KAMPUNG UJUNG	0,4823	9
SECT_TUWUNG	0,4762	10
…	…	…
LBS ANOA	0,3731	119
REC_BULILI (EX PANORAMA)	0,3723	120
SECT_TRANS	0,3713	121
SECT_KALIBU	0,3651	122
SECT_RUJAB EREKE	0,3603	123
SECT_MANDATI	0,3551	124
REC_WAGARI	0,2452	125
REC_SATRIYO	0,1913	126
REC_KONDOWA	0,0896	127
LBS TIKEP	0,0301	128

In the TOPSIS method, the best alternative is the alternative with the largest preference value. From Table 14 it can be seen that the alternative keypoint with the largest preference value is SECT_TAIPA.

Sensitivity Analysis

In this study, the weight of the largest criterion was reduced by 10%, while the other criteria were increased proportionally, then the weight of the largest criterion was increased by 10%, while the other criteria were decreased proportionally. Changes in weight can be seen in Table 15.

Table 15
Sensitivity Analysis

Criterion	Initial Weight	Highest weight Increased by 10% (Other Weights Decreased by 10%)	Highest weight Decreased by 10% (Other Weights Increased by 10%)
ENS	0,1395	0,1256	0,1535
Keypoint Load	0,0907	0,0816	0,0998
Load Profile Served	0,2034	0,1831	0,2237
SCADA Integration Cost	0,3352	0,3687	0,3017
Keypoint distance from unit office	0,1989	0,1790	0,2188
Number of Disturbances/Trips	0,0323	0,0291	0,0355

Changes in the alternative keypoint ranking results are then evaluated using the TOPSIS method by the weight changes above. It was found that there was no significant change to the sequence of alternative keypoints. The keypoint alternative with the highest preference value is always the same at every change in criteria weight. The keypoint alternative with the lowest preference value also does not change.

Standard deviation is a value that shows the level (degree) of variation in a data group or a standard measure of deviation from the mean. The standard deviation of all preference value data also does not change significantly before and after changing the weights. Therefore, it can be concluded that the decisions produced based on the TOPSIS method are robust or consistent.

Initial preference values and after changes to keypoint alternatives can be seen in Table 16.

Table 16
Changes of Preference Value

Keypoint	Initial Value	Initial Rank	Value +10%	Rank +10%	Value -10%	Rank - 10%
SECT_TAIPA	0,6606	1	0,6802	1	0,6448	1
SECT_CEMPA WELADO	0,5951	2	0,6265	2	0,5676	2
REC_LEMBU	0,5753	3	0,6041	3	0,5510	3
REC_LASOLO	0,5081	4	0,5477	4	0,4722	4
REC_BUPATI KONSEL	0,5070	5	0,5476	5	0,4697	5
REC_BIMA MAROA	0,5003	6	0,5427	6	0,4609	7
REC_ROMPU-ROMPU	0,4963	7	0,5302	8	0,4671	6
SECT_PANJUTANA	0,4947	8	0,5378	7	0,4544	9
REC_KAMPUNG UJUNG	0,4823	9	0,5124	10	0,4572	8
SECT_TUWUNG	0,4762	10	0,5220	9	0,4326	10
…	…	…	…	…	…	…
LBS ANOA	0,3731	119	0,4207	118	0,3277	120
REC_BULILI (EX PANORAMA)	0,3723	120	0,4189	120	0,3282	118
SECT_TRANS	0,3713	121	0,4184	121	0,3266	121
SECT_KALIBU	0,3651	122	0,4110	122	0,3217	122
SECT_RUJAB EREKE	0,3603	123	0,4057	123	0,3177	123
SECT_MANDATI	0,3551	124	0,4009	124	0,3118	124
REC_WAGARI	0,2452	125	0,2303	125	0,2577	125
REC_SATRIYO	0,1913	126	0,1788	126	0,2019	126
REC_KONDOWA	0,0896	127	0,0860	127	0,0928	127
LBS TIKEP	0,0301	128	0,0342	128	0,0261	128
Deviation	**0,0662**		**0,0712**		**0,0633**	
Changes	**-**		**7,42%**		**4,49%**	

Impact of Research on Companies

The research on Determination of SCADA Integration Priority at Keypoints using Fuzzy AHP and TOPSIS Method has an impact on decision-making in determining SCADA integration at keypoints in PLN UP2D Makassar. This method facilitates the company in making decisions regarding which keypoints will be integrated with SCADA first. PLN UP2D Makassar is allocated different budgets each year for the keypoint integration program into SCADA. Integration that does not consider the priority of each keypoint, which has the highest impact on KPIs, will result in ineffective budget allocation. Therefore, the FAHP TOPSIS method is needed to assist decision-makers in determining the priority of alternative keypoints, so that the costs incurred have a significant impact on KPIs. The use of this method will optimize the budget allocation given to PLN UP2D Makassar to be more targeted, as it is determined based on priority scale.

Conclusion

The following conclusions are drawn from the research conducted to determine the priority of keypoint integration with SCADA using the Fuzzy AHP-TOPSIS Method in PT PLN (Persero) UP2D Makassar.

1. Of the total 6 (six) criteria, the criteria with the highest weight in determining keypoint integration with SCADA are SCADA integration cost (0.3352), load profile served (0.2034), keypoint distance from unit office (0.1989), and ENS (0.1395). The weighting was done using the Fuzzy AHP method and resulted in a consistency ratio of -0.008. Thus, the weighting result is declared valid.
2. The weight of the criteria resulting from the FAHP method is then sorted by the TOPSIS method. The highest preference value of 0.6593 was obtained at the key point SECT_TAIPA, the most prioritized alternative to SCADA integration. The lowest preference value is 0.0301 on the LBS_TIKEP keypoint alternative.
3. After sensitivity analysis, the top 5 (five) sequences were obtained that did not change, then experienced changes in ranking, but with deviations that were not too large. Likewise, with the bottom 8 (eight) priority key point alternatives. Thus, it can be concluded that the data produced is robust or consistent.

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