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Priority Selection of Fiohl (Fault Indicator Over Head Line) Installation Location Using the Entropy Method - Promethee

Akhmad Budianto, Udisubakti Ciptomulyono
Institut Teknologi Sepuluh Nopember, Indonesia
Email: 6032231240@student.its.ac.id, udisubakti@ie.its.ac.id

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Abstract. The main challenge in electricity distribution in Riau and Riau Islands is the high incidence of power line faults. One effort to reduce power line faults involves the installation of *FIOHL* (Fault Indicator Overhead Line). *FIOHL* is a device used to detect faults on power lines, which can help quickly identify the location of the fault. In this study, *PLN UP2D Riau* plans to install 35 *FIOHL* units on 198 power lines. The objective of this study is to determine the accurate priority order of power lines for installing *FIOHL*s. By using the *Entropy* method as a criterion weighting method and *PROMETHEE* (Preference Ranking Organisation Method for Enrichment Evaluations), the priority order of alternative solutions for determining the power lines can be obtained. The installation of *FIOHL* must meet eight criteria: number of outages, outage duration, Energy Not Served (ENS), number of outages without cause, feeder load, network length, number of customers, and keypoint ratio for each feeder. The number of customers has the highest weight at 0.175, followed by network length at 0.152 and ENS at 0.151. The priority locations for *FIOHL* installation using the *PROMETHEE* method show that the Maroko feeder ranks first with *Phi* = 0.6329, followed by the Laos feeder with *Phi* = 0.6247. The allocation of *FIOHL* installations across each Implementation Unit (*UP3*) includes 14 units for *UP3 Bangkinang*, 14 units for *UP3 Dumai*, 4 units for Pekanbaru, and 3 units for *UP3 Rengat*.

Keywords: Reliability of Electrical Networks; Feeders; FIOHL; Entropy; PROMETHEE; Location Determination

INTRODUCTION

According to (PLN UP2D Riau 2024) The electricity system of Riau and Riau Islands is interconnected with the Sumatra system which consists of 3 major sub-systems, namely Northern Sumatra, Central Sumatra, and Southern Sumatra. Riau, West Sumatra, and Jambi are members of the Central Sumatra sub-system and have a Sub-System in Batam-Bintan and the MCTN Sub-System which includes the Pertamina Hulu Rokan refinery with a total supply capacity of 1,758 MW. The Riau and Riau Islands systems themselves have the highest peak load in September 2024 of 1,568 MW.

The number of substations (GI) in the Riau and Riau Islands working areas is 26 GIs with a capacity of 2360 MVA. The working area of PT PLN (Persero) UP2D Riau covers the entire area of Riau Province and Riau Islands Province consisting of 19 districts/cities, bordering the provinces of North Sumatra, West Sumatra and Jambi. UP2D serves the operation of a 20 kV distribution system in the work area of UP2D Riau which includes 5 UP3s, namely UP3 Pekanbaru, UP3 Dumai, UP3 Rengat, UP3 Tanjung Pinang, and UP3 Bangkinang.

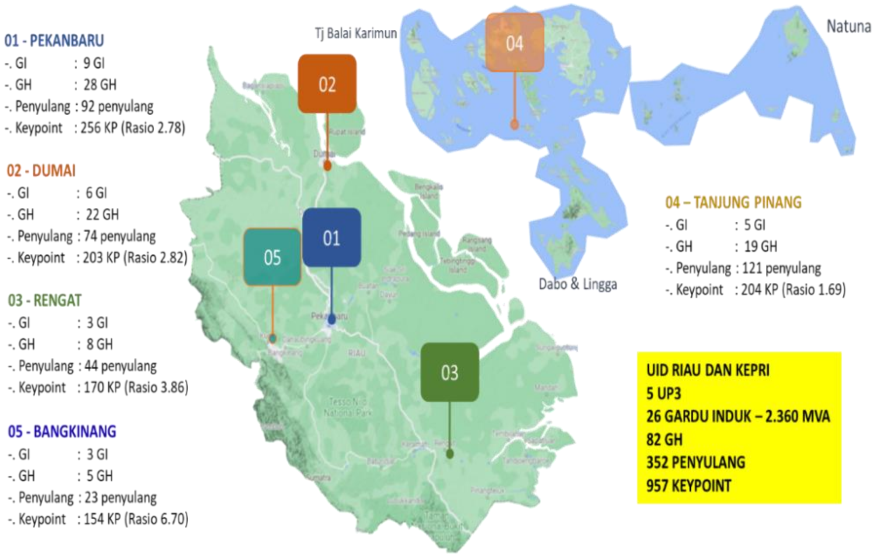

Figure 1. PLN UP2D Riau Business Data
Source: (PLN UP2D Riau 2023)

The demand forecast for PLN UID Riau and the Riau Islands in 2023 to 2024 is estimated to increase from 1348 MW (1149 + 199 MW) to 1519 MW (1308 + 211 MW) or 12.68%. Meanwhile, for 2025, the peak load of Riau and Riau Islands is estimated to increase by 11.12% to 1688 MW (1463 + 225 MW) (PLN UP2D Riau 2023).

PLN UP2D Riau is committed to continuing to make improvements, especially in terms of network reliability, this is evidenced by the achievement *of SAIDI/SAIFI* performance that is improving, namely *SAIDI* with a realization of 282.60 minutes/customer from the target of 381.75 minutes/customer and *SAIFI* with a realization of 3.78 times/customer from the target of 4.80 times/customer in December 2023. The realization of *SAIDI/SAIFI's* performance in 2023 was dominated by disruptions, as shown in the following table:

Table 1. Realization *SABA* / *SAIFI* 2023

Source: (PLN UP2D Riau 2023)

CAUSE	*SABA*		*SAIFI*	
	MIN/PLG	**%**	**KALI/PLG**	**%**
GANGGUAN	210,0	74%	3,02	80%
MAINTENANCE	70,8	25%	0,74	19%
NATURAL DISASTER	1,6	1%	0,02	1%
TOTAL	**282,4**	**100**	**3,78**	**100**

In 2029, PT PLN (Persero) UP2D Riau projects the *SAIDI/SAIFI value* of 260.24 minutes/plg and 3.15 times/plg, so it takes strategic and effective efforts to be able to achieve the set target. The current condition of *the FIOHL* ratio is 1 : 0.03 and still needs to be improved, combined with the addition of a key point to cover the feeder with a JTM length of > 150 kms and has many branches.

From the points above, one of the efforts made to improve performance *SABA* / *SAIFI* is the installation *FIOHL* on a 20 kV network. *FIOHL* It is essential to improve the reliability and efficiency of the power distribution system by facilitating rapid localization of faults. Its implementation reduces the duration of outages and related economic losses by minimizing inspection time and maintenance costs. Studies highlight that *FIOHL* It is especially important in complex distribution networks with extensive branching, where manual fault detection requires a lot of labor and is prone to errors (Coanda et al., 2022; Jeong et al., 2019; Xia et al., 2021). Modern advances have integrated fault indicators with high-precision detection technology, improving fault identification even in challenging environments (Alam et al., 2022; Derakhshandeh & Nikbakht, 2018; He et al., 2020; B. Li et al., 2020; W. Li et al., 2017; Recioui et al., 2021; Santos & Vieira, 2021)

The determination of the location of the *FIOHL* installation is sought to be on target so that a special decision-making strategy is needed to determine the right feeder location for *the installation of FIOHL.* Problems in prioritizing *FIOHL* placement can be subjective or objective depending on the facts on the ground. For example, *SAIDI SAIFI* is considered a more important criterion in placing *FIOHL* because it is one of the main performances while on the other hand the criterion of network length or feeder load is considered more important because the placement of *FIOHL is* needed in the network to accelerate the localization of interference. This phenomenon is called *conflicting criteria*. This complexity makes traditional approaches often less effective in providing comprehensive solutions. There is a multicriteria decision-making methodology, namely the multicriteria decision-making approach (*MCDM*).

Multiple Criteria Decision Making (MCDM) is a systematic approach used to solve decision-making problems by considering many often-conflicting criteria. *MCDM* provides a framework for evaluating and comparing alternatives based on a variety of factors, resulting in more objective and rational decisions. (Cardoso et al. 2022).

Method *Entropy* especially relevant in situations where data is diverse or incomplete. This method does not require subjective input from the decision-maker, such as initial weight, which can create bias. This makes it particularly suitable for cases such as priority location, where each criterion (e.g., cost, risk, or benefit) has a different role, but is difficult to compare directly (X. Zhang et al. 2024). Another advantage of this method is its ability to provide transparent and replicative results. The weight calculation process using *Entropy* follows clear mathematical steps, so that it is easy to understand by different stakeholders and allows for reanalysis if necessary (C. Chen, 2020; C. H. Chen, 2020, 2021; Cui et al., 2023).

Method *PROMETHEE* (*Preference Ranking Organization Method for Enrichment Evaluations*) excels at evaluating alternatives when involving conflicting criteria, offering clear ratings and sensitivity analysis. Its durability and ease of implementation make it the preferred tool in electric power system optimization. *PROMETHEE* effectively address the trade-offs between operational efficiency, economic considerations, and disruption localization accuracy, thus guiding strategic FI placement decisions (Taherdoost, 2023).

From the background of the problems that have been explained and based on the literature study, a research gap is obtained that shows that no one has applied the decision-making method in determining the priority of the installation location of FIOHL. Therefore, the formulation of the problems at PT PLN UP2D Riau is related to several aspects, including how to identify criteria in determining the priority of FIOHL installation at PT PLN UP2D Riau, how to measure the weight of each FIOHL installation criteria, and how to assess and rank alternatives based on conflicting criteria that will be installed by FIOHL. In addition, it is also important to know how many FIOHL allocation units will be installed in each UP3 in Riau.

The purpose of this study is to identify criteria in determining the priority of FIOHL installation at PT PLN UP2D Riau, measure the weight of each FIOHL installation criteria using the Entropy method, assess and rank alternatives based on conflicting criteria using the PROMETHEE method, and make an allocation of FIOHL installation in each UP3 in Riau.

The benefits of this study include providing priority solutions for determining feeders as the location of FIOHL placements, becoming an analysis model that can be implemented for evaluating the reliability performance of the power grid, and providing managerial implications with the use of the analysis method applied in this study.

The limitations of this research problem include the limited electricity system in the working area of PT PLN UP2D Riau with a total of 198 feeders. This study also did not take into account the feeder with the TM Ground Cable Channel (SKTM) in the decision-making due to the different construction process. In addition, feeders in isolated systems and plant outputs are not taken into account in decision-making.

Previous research has explored various fault detection and network reliability methods, including the use of fault indicators to improve service continuity in power systems. Xia et al. (2021) discussed the importance of advanced detection systems in reducing fault localization time, while Santos & Vieira (2021) highlighted the application of precision fault detection in complex distribution networks. Despite these advances, a comprehensive decision-making approach that addresses conflicting criteria in the placement of FIOHLs has not been widely applied in the context of PT PLN UP2D Riau. This represents a significant gap in the current research, as previous studies have primarily focused on isolated criteria or did not provide a multi-criteria approach that combines technical and operational considerations.

The novelty of this research lies in the application of the Entropy method for weighting criteria and the PROMETHEE method for ranking alternatives, a combination that has not been explored in prior studies for FIOHL placement. This approach provides a systematic and objective method for prioritizing feeder locations based on multiple conflicting criteria, such as outage frequency, feeder load, network length, and customer density. The study aims to bridge this gap by offering a practical model for decision-making in the installation of FIOHLs that balances both operational efficiency and network reliability.

The primary objectives of this study are to identify and weigh the criteria used to prioritize FIOHL installation at PT PLN UP2D Riau, assess and rank the feeder locations based on the conflicting criteria using the PROMETHEE method, and allocate FIOHL units across various UP3s in Riau based on the ranked priority. This research provides several key benefits: it offers a decision-making framework for FIOHL installation that can be replicated in similar regions or utilities, contributes to improving the reliability of the electricity distribution system by ensuring that FIOHL units are installed in the most critical locations, and provides managerial insights for optimizing resource allocation in the power distribution network, thereby enhancing operational efficiency and reducing maintenance costs.

RESEARCH METHODS

The methodology for selecting priority sites for *FIOHL* installation at *PT PLN UP2D Riau* begins with identifying the problem of frequent *feeder* disturbances and setting research objectives, followed by literature and field studies to establish selection criteria. Data is collected through interviews, *Focus Group Discussions (FGD)*, and operational reports, then processed using the *Entropy* method for weighting criteria and the *PROMETHEE II* method for ranking locations. Sensitivity analysis is conducted to ensure the reliability and stability of the decision model by adjusting criterion weights and reordering alternatives. The results identify the most prioritized locations and dominant decision criteria, with managerial implications including improved resource allocation, enhanced network reliability, and strengthened analytical capabilities among managers.

RESULTS AND DISCUSSION

Criteria Data

This study uses eight main criteria to determine the priority of *FIOHL installation* in improving the reliability of the power grid. The table below describes the name of the criteria, the criteria code and the types of their attributes which are classified into *Benefit* and *Cost*. For more details, you can see the following table:

No	KRITERIA	KODE KRITERIA	TIPE ATRIBUT
1	Kali Gangguan	C1	Benefit
2	Durasi Gangguan	C2	Benefit
3	ENS	C3	Benefit
4	Kali Gangguan Tidak Ditemukan Penyebab	C4	Benefit
5	Beban Penyulang	C5	Benefit
6	Panjang Jaringan	C6	Benefit
7	Jumlah Pelanggan	C7	Benefit
8	Rasio Keypoint	C8	Cost

Table 1. Criteria Data and Attribute Type
Source : Data by Researcher

The explanation for each criterion is as follows:

1. Time Interruption (C1)
   Time of disruption is an indicator to measure the frequency of power outages experienced by consumers. Smaller interference times values indicate better network reliability, whereas larger values indicate lower levels of reliability. *FIOHL* is prioritized to be installed on feeders with higher interference times so this criterion includes the *Benefit type*.
2. Duration of Interruption (C2)
   The duration of the outage is an indicator to measure the length of the electrical power outage experienced by consumers. Smaller fault duration values indicate better network reliability, whereas larger values indicate lower levels of reliability. *FIOHL* is prioritized to be installed on feeders with a higher duration of interference so that this criterion is included in the *Benefit type*.
3. *ENS* (C3)

ENS (Energy Not Serve) is an indicator to calculate the amount of energy that cannot be distributed to consumers due to electrical power interruptions. A smaller *ENS* value indicates better network reliability, whereas a larger value indicates a lower level of reliability. *FIOHL* is prioritized to be installed on feeders with higher *ENS* so this criterion includes the *Benefit type*.

4. Time Disruption No Cause Found (C4)
   The time the fault is not found is an indicator to measure the time the electrical power interruption experienced by the consumer with the cause of the fault not found. A higher value indicates the risk of recurrence of the disorder. *FIOHL* is prioritized to be installed on feeders with higher grades so that this criterion is included in the *Benefit type*.
5. Feeder Load (C5)
   The feeder load is an indicator of the amount of electricity consumption by the customer. A greater value indicates a higher level of importance. *FIOHL* is prioritized to be installed on feeders with larger feeder loads, so this criterion is included in the *Benefit type*.
6. Network Length (C6)
   Network length refers to the total length of feeder in a distribution system. The shorter the network, the less chance of disruption occurring. *FIOHL* is prioritized for being installed on feeders with longer network lengths so this criterion is included in the *Benefit type*.
7. Number of Customers (C7)
   The number of customers is an indicator of the number of customers who consume electricity. A greater value indicates a higher level of importance. *FIOHL* is prioritized to be installed on feeders with a larger number of customers, so this criterion is included in the *Benefit type*.
8. Rasio Keypoint (C8)
   The keypoint ratio shows the number of key points on the feeder used in the operation of electric power distribution. The greater the number of key points will speed up the fault recovery process, the smaller the key point ratio, the more necessary it is to install *FIOHL*. *FIOHL* is prioritized to be installed on the feeder with a larger number of customers so that this criterion includes the Cost type.

In general, the criteria with *the Benefit* type indicate that higher values are prioritized for *FIOHL installation*, while the Cost type criteria mean that smaller values are prioritized. An understanding of each of these criteria allows the decision-making process to be carried out systematically to determine the most effective *FIOHL* installation priorities.

Weighting of Selection Criteria Using Entropy

1. Creating a Decision Matrix

The criteria used in this study amounted to 8 and the alternatives used amounted to 198 feeders, so that the decision matrix was 198 x 8. The elements of the decision matrix are the result of collecting data from various sources. The results matrix uses equations (2.1) in Chapter 2.

The decision matrix in this study can be seen in the following table:

No	ALTERNATIF PENYULANG	KRITERIA							
		KALI GANGGUAN	DURASI GANGGUAN	ENS	KALI GANGGUAN TIDAK DITEMUKAN PENYEBAB	BEBAN PENYULANG	PANJANG JARINGAN	JUMLAH PELANGGAN	RASIO KEYPOINT
		(KALI)	(MENIT)	(KWH)	(KALI)	(AMPERE)	(KMS)	(PELANGGAN)	(KALI)
1	PAKISTAN	54	528	15.874	48	172	153	23.546	2
2	VIETNAM	12	166	3.290	8	108	22	15.264	2
3	LAOS	85	2.189	62.465	70	150	248	13.817	2
4	MALAYSIA	129	2.277	67.972	111	187	182	17.043	8
5	QATAR	63	1.094	33.438	50	223	41	42.834	2
6	SINGAPURA	104	2.602	156.970	55	157	238	28.680	8
7	HONGKONG	28	281	2.493	23	15	23	21.851	2
8	JEPANG	111	907	26.919	87	212	101	36.947	4
9	KORSEL	28	297	6.608	11	132	32	15.508	1
10	MONGOLIA	82	744	24.605	61	136	92	23.145	1
11	TAIWAN	102	1.105	33.973	58	139	91	23.797	2
12	KAMERUN	55	976	22.758	30	139	94	23.781	5
13	KONGO	73	2.003	58.059	56	134	194	13.604	6
14	MESIR	70	1.219	89.562	44	258	161	14.576	4
15	MAROKO	171	6.346	324.928	33	301	188	25.534	6
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
194	SANUR	23	20	293	10	30	2	680	3
195	ARABIA	11	53	1.517	2	79	7	9.571	6
196	PATAGONIA	36	54	1.039	8	58	68	10.851	6
197	SAHARA	31	69	580	6	56	54	9.596	4
198	TANJUNG	0	0	0	0	2	1	238	0

Table 2. Results Matrix
Source: Data by Researcher

Normalizing the Decision Matrix

Normalization is used to change the scale of the values of each criterion to be comparable to each other. The normalization of the decision matrix is carried out using equation (2.2) in Chapter 2.

The normalized decision matrix can be seen in the following table:

1	PAKISTAN	0,189	0,083	0,049	0,208	0,571	0,440	0,346	0,050
2	VIETNAM	0,042	0,026	0,010	0,035	0,359	0,063	0,224	0,050
3	LAOS	0,297	0,345	0,192	0,303	0,498	0,713	0,203	0,050
4	MALAYSIA	0,451	0,359	0,209	0,481	0,621	0,523	0,250	0,013
5	QATAR	0,220	0,172	0,103	0,216	0,741	0,118	0,629	0,050
6	SINGAPURA	0,364	0,410	0,483	0,238	0,522	0,684	0,421	0,013
7	HONGKONG	0,098	0,044	0,008	0,100	0,050	0,066	0,321	0,050
8	JEPANG	0,388	0,143	0,083	0,377	0,704	0,290	0,542	0,025
9	KORSEL	0,098	0,047	0,020	0,048	0,439	0,092	0,228	0,100
10	MONGOLIA	0,287	0,117	0,076	0,264	0,452	0,264	0,340	0,100
11	TAIWAN	0,357	0,174	0,105	0,251	0,462	0,261	0,349	0,050
12	KAMERUN	0,192	0,154	0,070	0,130	0,462	0,270	0,349	0,020
13	KONGO	0,255	0,316	0,179	0,242	0,445	0,557	0,200	0,017
14	MESIR	0,245	0,192	0,276	0,190	0,857	0,463	0,214	0,025
15	MAROKO	0,598	1,000	1,000	0,143	1,000	0,540	0,375	0,017
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
194	SANUR	0,080	0,003	0,001	0,043	0,100	0,006	0,010	0,033
195	ARABIA	0,038	0,008	0,005	0,009	0,262	0,020	0,140	0,017
196	PATAGONIA	0,126	0,009	0,003	0,035	0,193	0,195	0,159	0,017
197	SAHARA	0,108	0,011	0,002	0,026	0,186	0,155	0,141	0,025
198	TANJUNG	0,000	0,000	0,000	0,000	0,007	0,003	0,003	1,000
	TOTAL	41,38	28,92	22,48	34,79	83,02	34,71	20,91	10,03

Table 3. Normalized Decision Matrix
Source : Data by Researcher

Calculating the Proportion Value

The proportion for elements in the normalized decision matrix is calculated by dividing the value of that element by the values of the elements in the same column (criterion j). The calculation of the proportion value uses the equation (2.3) in Chapter 2.p_{ij} r_{ij}

The Proportion value in the study can be shown in the following table:

1	PAKISTAN	0,005	0,003	0,002	0,006	0,007	0,013	0,017	0,005
2	VIETNAM	0,001	0,001	0,000	0,001	0,004	0,002	0,011	0,005
3	LAOS	0,007	0,012	0,009	0,009	0,006	0,021	0,010	0,005
4	MALAYSIA	0,011	0,012	0,009	0,014	0,007	0,015	0,012	0,001
5	QATAR	0,005	0,006	0,005	0,006	0,009	0,003	0,030	0,005
6	SINGAPURA	0,009	0,014	0,021	0,007	0,006	0,020	0,020	0,001
7	HONGKONG	0,002	0,002	0,000	0,003	0,001	0,002	0,015	0,005
8	JEPANG	0,009	0,005	0,004	0,011	0,008	0,008	0,026	0,002
9	KORSEL	0,002	0,002	0,001	0,001	0,005	0,003	0,011	0,010
10	MONGOLIA	0,007	0,004	0,003	0,008	0,005	0,008	0,016	0,010
11	TAIWAN	0,009	0,006	0,005	0,007	0,006	0,008	0,017	0,005
12	KAMERUN	0,005	0,005	0,003	0,004	0,006	0,008	0,017	0,002
13	KONGO	0,006	0,011	0,008	0,007	0,005	0,016	0,010	0,002
14	MESIR	0,006	0,007	0,012	0,005	0,010	0,013	0,010	0,002
15	MAROKO	0,014	0,035	0,044	0,004	0,012	0,016	0,018	0,002
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
194	SANUR	0,002	0,000	0,000	0,001	0,001	0,000	0,000	0,003
195	ARABIA	0,001	0,000	0,000	0,000	0,003	0,001	0,007	0,002
196	PATAGONIA	0,003	0,000	0,000	0,001	0,002	0,006	0,008	0,002
197	SAHARA	0,003	0,000	0,000	0,001	0,002	0,004	0,007	0,002
198	TANJUNG	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,100

Table 4. Proportion Value

Source : Data by Researcher

Calculating the *Entropy Value*

The Entropy *value* is used to measure the uncertainty in the data distribution of a criterion. The greater the uncertainty in the value distribution of a criterion, the greater the entropy value. The *Entropy* value is also used to determine how informative a criterion is. The calculation of *the value of Entropy* uses the equation (2.4) in Chapter 2.

The results of the calculation of *the Entropy* value can be shown in the following table:

E1	0,925
E2	0,905
E3	0,892
E4	0,904
E5	0,963
E6	0,888
E7	0,871
E8	0,916

Table 1. Nilai Entropy

Source: Data by Researcher

Calculating the Initial Value *of Entropy* (Dispersion)

Dispersion is the opposite of *Entropy* which means the higher the *value of Entropy*, the lower the value of the dispersion and vice versa. The calculation of the initial value *of Entropy* (dispersion) is shown in equation (2.5) Chapter 2.

The results of the calculation of the initial value *of Entropy* (dispersion) can be shown in the following table:

D1	0,0725
D2	0,0907
D3	0,1976
D4	0,0930
D5	0,0292

Table 6. Initial Value *Entropy* (Missing)

Source : Data by Researcher

Calculating the End Weight *of Entropy*

The weight of criteria shows the relative importance of each criterion in decision-making. This weight is calculated by normalizing the value of the dispersion with the equation (2.6) Chapter 2.

The results of the calculation of the final *weight of Entropy* can be shown in the following Table 11:

Kode	Bobot	Nama Kriteria
W1	0,102	Kali Gangguan
W2	0,129	Durasi Gangguan
W3	0,146	ENS
W4	0,130	Kali Gangguan Tidak Ditemukan Penyebab
W5	0,051	Beban Penyulang
W6	0,152	Panjang Jaringan
W7	0,175	Jumlah Pelanggan
W8	0,114	Rasio Keypoint
	1,0000	

Table 7. Final Weight *Entropy*

Source : Data by Researcher

From Table 7, it can be explained that the number of customers has the highest weight with a weight of 0.175, then the length of the network with a weight of 0.152 and *ENS* with a weight of 0.146. The lowest weight is the feeder load criterion with a weight of 0.051.

Determination of Alternative Rankings with the *PROMETHEE Method*

Determining Function Types, Preferences, and Parameters

One of the main advantages of the *PROMETHEE* method is its ability to accommodate different types of decision-making preferences using the preference function. In simple terms, the preference function is *PROMETHEE's way* of translating how much an alternative is better than another based on the difference in value in a given criterion.

There are six types of preference functions (Mareschal et al., 1984) that allow the model to handle a wide range of situations and criteria characteristics. A further explanation of the types of preference functions has been described in chapter 2.7.

In this study, the type of preference and threshold value can be explained in the following table:

No	KRITERIA	KODE KRITERIA	TIPE ATRIBUT	BOBOT	TIPE PREFERENSI	NILAI AMBANG BATAS	SATUAN
1	Kali Gangguan	C1	Benefit	0,102	V - Shape (P 3)	p = 12	Kali
2	Durasi Gangguan	C2	Benefit	0,129	V - Shape (P 3)	p = 60	Menit
3	ENS	C3	Benefit	0,146	V - Shape (P 3)	p = 1000	kWh
4	Kali Gangguan Tidak Ditemukan Penyebab	C4	Benefit	0,130	V - Shape (P 3)	p = 12	Kali
5	Beban Penyulang	C5	Benefit	0,051	Linear (P 5)	q = 30 ; p = 200	Ampere
6	Panjang Jaringan	C6	Benefit	0,152	Linear (P 5)	q = 35 ; p = 69	kms
7	Jumlah Pelanggan	C7	Benefit	0,175	Linear (P 5)	q = 4.886 ; p = 9.771	Pelanggan
8	Rasio Keypoint	C8	Cost	0,114	Linear (P 5)	q = 1 ; p = 2	Kali

Table 8. Type Preferences and Threshold Values

Source: Data by Researcher

The explanation for each criterion is as follows:

2. Time Interruption (C1)

   Outage times are an indicator to measure the times of power outages experienced by consumers. This criterion falls under the *V-Shape preference type* (P 3) because the interference times there is no neutral zone, the slightest difference in interference times has different preferences.

   The *preference threshold* value *(p)* is determined based on reliability guidelines where the feeder is said to be healthy if there is a disturbance 1 time in 1 month or 12 times a year. So that the threshold value $p = 12$.

3. Duration of Interruption (C2)

   The duration of the outage is an indicator to measure the length of the electrical outage experienced by consumers. This criterion is included in the *V-Shape preference type* (P 3) because the duration of the disturbance is not a neutral zone, the slightest difference in the duration of the disturbance has different preferences.

   The *preference threshold value (p)* is determined based on reliability guidelines where the feeder is said to be healthy if there is a disturbance of less than 5 minutes in 1 month or 60 minutes in a year. So that the threshold value $p = 60$.

4. *ENS* (C3)

   ENS (*Energy Not Serve*) is an indicator to calculate the amount of energy that cannot be delivered to consumers due to power outages. This criterion falls under the *V-Shape* preference type (P 3) because *the ENS* does not have a neutral zone, the slightest *difference in ENS* has different preferences.

   The preference *threshold value (p)* is determined based on reliability guidelines where the feeder is said to be healthy in the event of a disturbance of less than 1000 kWh in a year. So that the threshold value $p = 1000$.

5. Time Disruption No Cause Found (C4)

   This criterion is included in the *V-Shape* preference type (P 3) because when interference is not found there is no neutral zone, the slightest difference has different preferences.

The preference *threshold* value (p) is determined based on reliability guidelines where the feeder is said to be healthy in the event of a disturbance 1 time in 1 month or 12 times a year. So that the threshold value p = 12.

6. Feeder Load (C5)

The feeder load is an indicator of the amount of electricity consumption by the customer. This criterion is included in the Linear preference type (P 5) because the feeder load has a neutral zone that is considered not too significant.

The preference *threshold value* (p) and *indifference threshold* (q) are determined based on reliability guidelines where the feeder is said to be healthy when operating in the range of 30 – 200 Amperes. So that the threshold value q = 30 and indigo p = 200.

7. Network Length (C6)

Network length refers to the total length of feeder in a distribution system. This criterion is included in the Linear preference type (P 5) because the length of the network has a neutral zone that is considered not too significant.

The value of the preference *threshold* (p) and *the indifference threshold* (q) has not been determined so it is determined based on the statistical calculation of the standard deviation, then validated by the opinions of experts.

Known Standard Deviation value = 69

- *Indifference Threshold (q)* = 50% x standard deviation = 50% x 69 = 35
- *Preference Threshold (p)* = 100 % x standard deviation = 100 % x 69 = 69

So that the threshold value *is* q = 35 and *the value* p = 69.

8. Number of Customers (C7)

The number of customers is an indicator of the number of customers who consume electricity. This criterion is included in the Linear preference type (P 5) because the number of customers in the neutral zone is considered not very significant.

The value of the preference threshold (p) and *the indifference threshold* (q) is also not yet determined so it is determined based on the statistical calculation of the standard deviation, then validated by the opinions of experts.

Known Standard Deviation value = 9.771

- *Indifference Threshold (q)* = 50% x standard deviation = 50% x 9771 = 4.886
- *Preference Threshold (p)* = 100% x standard deviation = 100% x 9771 = 9.771.

So that the threshold value *of* q = 4.886 and *the value of* p = 9.771.

9. Rasio Keypoint (C8)

The key point ratio shows the number of key points used in the operation of electric power distribution. This criterion is included in the Linear preference type (P 5) because the key point ratio has a neutral zone that is considered not too significant.

The value of the preference threshold (p) and *the indifference threshold* (q) is also not yet determined so it is determined based on the statistical calculation of the standard deviation, then validated by the opinions of experts.

Known Standard Deviation value = 2

- *Indifference Threshold (q)* = 50% x standard deviation = 50% x 2 =1
- *Preference Threshold (p)* = 100 % x standard deviation = 100 % x 2 = 2

So that the threshold value q = 1 and *the value* p = 2.

Calculating the Value of the Preference Index

At this stage, several parameters such as criteria, alternatives, data values, attribute types, weights of the results of the *Entropy* method, preference type and threshold value (*threshold value*) are entered into the *Visual PROMETHEE software*.

The input of the decision matrix in *the Visual PROMETHEE software* can be explained in the following figure:

Scenario 1	Kali Gangguan	Durasi Gang...	ENS	Gangguan Ti...	Beban Peny...	Panjang Jari...	Jumlah Pelan...	Rasio Keypoint
Unit	Kali	Menit	kWh	Kali	MW	kms	Pelanggan	unit
Cluster/Group								
Preferences								
Min/Max	max	max	max	max	max	max	max	min
Weight	0,10	0,13	0,15	0,13	0,05	0,15	0,17	0,11
Preference Fn.	V-shape	V-shape	V-shape	V-shape	Linear	Linear	Linear	Linear
Thresholds	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute
- Q: Indifference	n/a	n/a	n/a	n/a	30	35	4886	1
- P: Preference	12	60	1000	12	200	138	19542	4
- S: Gaussian	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Statistics								
Minimum	0	0	0	0	2	1	2	0
Maximum	286	6346	324928	231	301	348	68141	13
Average	60	927	36885	41	126	61	7197	3
Standard Dev.	55	983	43087	43	66	69	9771	2
Evaluations								
PAKISTAN	54	528	15874	48	172	153	23546	2
VIETNAM	12	166	3290	8	108	22	15264	2
LAOS	85	2189	62465	70	150	248	13817	2
MALAYSIA	129	2277	67972	111	187	182	17043	8
QATAR	63	1094	33438	50	223	41	42834	2
SINGAPURA	104	2602	156970	55	157	238	28680	8
HONGKONG	28	281	2493	23	15	23	21851	2
JEPANG	111	907	26919	87	212	101	36947	4
KORSEL	28	297	6608	11	132	32	15508	1
MONGOLIA	82	744	24605	61	136	92	23145	1
TAIWAN	102	1105	33973	58	139	91	23797	2
KAMERUN	55	976	22758	30	139	94	23781	5
KONGO	73	2003	58059	56	134	194	13604	6
MESIR	70	1219	89562	44	258	161	14576	4
MAROKO	171	6346	324928	33	301	188	25534	6
JERMAN	16	482	18937	11	170	24	12471	3
PERANCIS	42	694	29553	32	160	34	27780	1
PORTUGAL	9	100	4544	7	170	10	3341	1
BELANDA	69	1281	42480	53	94	198	14637	2

Figure 9. Promethee Decision Matrix

The process of calculating the value of the paired preference index is not shown in *the Visual PROMETHEE software* because the process of calculating *leaving flow, entering flow and net flow is directly carried out.*

Calculating *Leaving Flow, Entering Flow and Net Flow Values*

Leaving outranking flow shows that many alternatives dominate other alternatives. *Entering outranking flow* shows the number of alternatives that are dominated by other alternatives. The calculation *of leaving flow, entering flow and net flow* values is based on equations (2.14), (2.15) and (2.16) in chapter 2.

The *PROMETHEE* II method can provide *a complete preorder* using *a net outranking flow* so that decisions become more realistic. The results of the calculation of *Leaving Flow* and *Entering Flow* in *the Visual PROMETHEE software* can be shown in the following table:

No	Nama Penyulang	Phi+	Phi-	Phi
1	PAKISTAN	0,5789	0,2531	0,3258
2	VIETNAM	0,2282	0,4553	-0,2271
3	LAOS	0,7252	0,1005	0,6247
4	MALAYSIA	0,7222	0,1717	0,5505
5	QATAR	0,5623	0,2049	0,3574
6	SINGAPURA	0,7493	0,1679	0,5814
7	HONGKONG	0,3276	0,4019	-0,0743
8	JEPANG	0,6531	0,2184	0,4347

No	Nama Penyulang	Phi+	Phi-	Phi
100	KESATRIAN	0,4903	0,2245	0,2658
101	LURIK	0,4637	0,202	0,2617
102	BELANGA	0,5988	0,1765	0,4223
103	PANGSI	0,4409	0,2545	0,1864
104	BATIK	0,5188	0,2511	0,2677
105	SONGKET	0,5721	0,2051	0,3669
106	BALAM	0,1801	0,4242	-0,2441
107	ELANG	0,1296	0,4947	-0,3651

Figure 10. *Leaving Flow, Entering Flow* and *Net Flow*

Determining Alternative Ratings

Rank all alternatives considered based on φ(i) values. A higher φ(i) value is a better alternative.

The results of ranking by *the PROMETHEE* method using *the PROMETHEE Visual software* can be shown in the following table:

Rank	Nama Penyulang	Phi	Phi+	Phi-
1	MAROKO	0,6329	0,7741	0,1411
2	LAOS	0,6247	0,7252	0,1005
3	SINGAPURA	0,5814	0,7493	0,1679
4	MALAYSIA	0,5505	0,7222	0,1717
5	DIENG	0,5408	0,6349	0,0941
6	KEMUNING	0,5317	0,6409	0,1092
7	ULOS	0,5186	0,6209	0,1023
8	ANGGREK	0,5154	0,6719	0,1565
9	SAFIR	0,51	0,6177	0,1077
10	SPINEL	0,5079	0,6578	0,1499
11	PRAMBANAN	0,487	0,6211	0,1342
12	MESIR	0,4853	0,6698	0,1844
.....	.....	.....	.....	.....
.....	.....	.....	.....	.....
.....	.....	.....	.....	.....
97	BELANAK	-0,0525	0,3016	0,3542
98	MERANTI	-0,0532	0,3277	0,3809
99	MERBAU	-0,0534	0,3035	0,3569

Rank	Nama Penyulang	Phi	Phi+	Phi-
100	SELAIS	-0,0548	0,2918	0,3466
101	ZAMRUD	-0,0552	0,2897	0,3449
102	SALMON	-0,0591	0,2779	0,337
103	VENUS	-0,0601	0,294	0,3541
104	SURIAN	-0,0704	0,2806	0,3509
105	HONGKONG	-0,0743	0,3276	0,4019
106	ARWANA	-0,0747	0,2754	0,3501
107	KORSEL	-0,0749	0,3114	0,3863
108	LEO	-0,0778	0,2885	0,3663
109	ARGENTINA	-0,0869	0,3199	0,4068
110	BUNTAL	-0,1016	0,2479	0,3495
111	TAURUS	-0,1067	0,2741	0,3808
.....	.....	.....	.....	.....
.....	.....	.....	.....	.....
.....	.....	.....	.....	.....
196	TANJUNG	-0,5268	0,088	0,6148
197	HARIMAU	-0,5396	0,0668	0,6064
198	GULLFOSS	-0,5444	0,0329	0,5774

Figure 11. Promethee Method Ranking Order

Source : Data by Researcher

From the table above, it can be explained that Moroccan feeders are ranked first with *Phi* = 0.6329 followed by Laos feeders *Phi* = 0.6247 and Singapore feeders with *Phi* = 0.5814. For the last ranking, it is the Gulfoss feeder with *Phi* = - 0.5444.

Sensitivity Analysis

After the alternative ranking is obtained, a sensitivity analysis is carried out to test the reliability of the model and the results of the decision. The application of Sensitivity analysis in the decision-making process is very important to ensure the robustness of the final decision.

In this study, sensitivity analysis was carried out in the following steps:

1. Change the weights of the dominant criteria as follows:
   a. The criteria with the largest weight were increased by 5%, 10%, 15% of the initial weight while the other criteria were reduced in weight proportionally to the increase in the weight of the largest criterion.
   b. The criteria with the largest weight were reduced by 5%, 10%, 15% of the initial weight while the other criteria were reduced in weight proportionally to the increase in the weight of the largest criterion.

   The change in the weight of the criteria can be seen in the following table:

KRITERIA	AWAL	DEVIASI NAIK			DEVIASI TURUN		
		5%	10%	15%	5%	10%	15%
KALI GANGGUAN	0,102	0,101	0,100	0,099	0,103	0,104	0,106
DURASI GANGGUAN	0,129	0,127	0,126	0,125	0,130	0,132	0,133
ENS	0,146	0,145	0,143	0,142	0,148	0,149	0,151
KALI GANGGUAN TIDAK DITEMUKAN PENYEBAB	0,130	0,129	0,128	0,126	0,132	0,133	0,134
BEBAN PENYULANG	0,051	0,050	0,050	0,049	0,051	0,052	0,052
PANJANG JARINGAN	0,152	0,151	0,149	0,148	0,154	0,156	0,157
JUMLAH PELANGGAN	0,175	0,184	0,193	0,202	0,166	0,158	0,149
RASIO KEYPOINT	0,114	0,113	0,112	0,110	0,115	0,116	0,118
	1,000	1,000	1,000	1,000	1,000	1,000	1,000

Figure 12. Weight Changes Criteria

Source : Data by Researcher

2. Reorder all alternatives back with *the PROMETHEE method*

After the weights of the criteria are changed, the recalculation of the ranking is determined by *the PROMETHEE method*. The results of this recalculation are then compared to the initial rankings obtained before the weights were changed. The results of the recalculation of the alternate sequence of the conditions of deviation up and down can be shown in the following table:

AWAL			NAIK 5 %			NAIK 10 %			NAIK 15 %		
Rank	Nama Penyulang	Phi	Rank	Nama Penyulang	Phi	Rank	Nama Penyulang	Phi	Rank	Nama Penyulang	Phi
1	MAROKO	0,6329	1	MAROKO	0,6352	1	MAROKO	0,6374	1	MAROKO	0,6418
2	LAOS	0,6247	2	LAOS	0,6245	2	LAOS	0,6237	2	LAOS	0,624
3	SINGAPURA	0,5814	3	SINGAPURA	0,5849	3	SINGAPURA	0,5875	3	SINGAPURA	0,5929
4	MALAYSIA	0,5505	4	MALAYSIA	0,5521	4	MALAYSIA	0,5533	4	MALAYSIA	0,5563
5	DIENG	0,5408	5	DIENG	0,5328	5	DIENG	0,5241	5	DIENG	0,5162
6	KEMUNING	0,5317	6	KEMUNING	0,5238	6	KEMUNING	0,515	6	KEMUNING	0,5067
7	ULOS	0,5186	7	ULOS	0,5109	7	ULOS	0,5029	7	ULOS	0,4952
8	ANGGREK	0,5154	8	ANGGREK	0,5072	8	ANGGREK	0,4984	8	ANGGREK	0,4918
9	SAFIR	0,51	9	SAFIR	0,5018	9	SAFIR	0,4931	9	MESIR	0,4901
10	SPINEL	0,5079	10	SPINEL	0,4998	10	SPINEL	0,4912	10	TAIWAN	0,4871

Figure 13. Change *Net Flow* Rising Deviation

Source : Data by Researcher

AWAL			TURUN 5 %			TURUN 10 %			TURUN 15 %		
Rank	Nama Penyulang	Phi	Rank	Nama Penyulang	Phi	Rank	Nama Penyulang	Phi	Rank	Nama Penyulang	Phi
1	MAROKO	0,6329	1	MAROKO	0,6303	1	MAROKO	0,6285	1	LAOS	0,6261
2	LAOS	0,6247	2	LAOS	0,6255	2	LAOS	0,626	2	MAROKO	0,6251
3	SINGAPURA	0,5814	3	SINGAPURA	0,5786	3	SINGAPURA	0,5758	3	SINGAPURA	0,5714
4	MALAYSIA	0,5505	4	DIENG	0,55	4	DIENG	0,5572	4	DIENG	0,5661
5	DIENG	0,5408	5	MALAYSIA	0,5496	5	MALAYSIA	0,5484	5	KEMUNING	0,5571
6	KEMUNING	0,5317	6	KEMUNING	0,5408	6	KEMUNING	0,5483	6	MALAYSIA	0,5457
7	ULOS	0,5186	7	ULOS	0,527	7	ULOS	0,5341	7	ULOS	0,5423
8	ANGGREK	0,5154	8	ANGGREK	0,5247	8	ANGGREK	0,5325	8	ANGGREK	0,5399
9	SAFIR	0,51	9	SAFIR	0,5189	9	SAFIR	0,5265	9	SAFIR	0,535
10	SPINEL	0,5079	10	SPINEL	0,517	10	SPINEL	0,5248	10	SPINEL	0,5322

Figure 14. Change *Net Flow* Deviation Down

Source : Data by Researcher

3. Analysis of Changes in Results

Alternate rank changes were analyzed to measure the sensitivity of the rank sequence to weight variations. If the ranking results remain consistent despite variations in weight, then the model is considered stable and reliable. From the results of the recalculation, when the weight of the criterion number of subscribers increased by 5% and 10%, there was no change in the order, but when the weight of the criterion number of subscribers increased by 15%, there were some changes in ranking but no significant changes.

Meanwhile, when the weight of the number of subscribers decreased, there were also some changes in ranking, but there were no significant changes. From the results of these calculations, it can be concluded that the decisions obtained based on the *PROMETHEE* method are *robust* or consistent.

Managerial Implications

The results of determining this priority order are a reference for recommendations for investment work plans for reliability improvement which will be implemented in stages in 2025 and 2026. The work plan for the installation *of FIOHL* is 35 units for 35 locations so that from the order of priority, the division per Customer Service Implementation Unit (UP3) is obtained as follows:

Unit Pelaksana	Tahap 1	Tahap 2	Jumlah
Bangkinang	7	7	14
Dumai	6	8	14
Pekanbaru	3	1	4
Rengat	1	2	3
Tanjungpinang	0	0	0
Jumlah	**17**	**18**	**35**

Figure 15. *FIOHL* Allocation Per Implementing Unit (UP3)

Source : Data by Researcher

The allocation of FIOHL Phase 1 (2025) for UP3 Bangkinang is 7 units, UP3 Dumai is 6 units, UP3 Pekanbaru is 3 units and UP3 Rengat is 1 unit. Meanwhile, the allocation for phase 2 (2026) for UP3 Dumai is 8 units, UP3 Bangkinang is 7 units, UP3 Pekanbaru is 1 unit and UP3 Rengat is 2 units.

CONCLUSION

The study on FIOHL installation prioritization at PT PLN UP2D Riau identified eight criteria, with the number of customers (weight: 0.175), network length (0.152), and ENS (0.151) being most influential, while feeder load (0.051) was least significant. Using the PROMETHEE method, Moroccan feeders ranked highest (Φ=0.6329) and Gulfoss feeders lowest (Φ=-0.5444). Allocations were 7, 6, 3, and 1 units for UP3 Bangkinang, Dumai, Pekanbaru, and Rengat in Phase 1, shifting to 8, 7, 2, and 1 units in Phase 2. For future research, applying alternative multi-criteria methods like AHP, TOPSIS, or ELECTRE is recommended to validate ranking consistency, alongside incorporating additional criteria such as extreme weather history, installation site accessibility, and network infrastructure age for more comprehensive decision-making.

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