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Reliability Analysis of 20 kV Distribution System in PT PLN (Persero) ULP Palopo Kota with Failure Mode and Effect Analysis (FMEA)

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Abstract. Fundamental problema in electricity distribution system are quality, continuity and availibility of electricity services for consumers. Failure Modes and Effect Analysis (FMEA) is one of the way to identify reliability index. From calculation of distribution system reliability in ULP Palopo Kota using FMEA method, Latuppa feeder shows results of SAIFI index : 8,91 failure/costumer.year and SAIDI index : 18,33 hour/costumer.year. Furthermore, Merdeka feeder shows result of SAIFI index : 1,916 failure/costumer.year and SAIDI index 3,478 hour/costumers.year. Frequencies of failure in the stream cause high number of failure in system compared with failure frequencies of distribution system equipment such as transformer, switch and CB, and so it affect SAIFI index number. On the other hand, SAIDI index number also got bigger following the long time of failure happens. To compensate for the high number of SAIFI and SAIDI index, fuse component and sectionalizer will be needed so that the system could perform reliably.

1. Introduction

In the aspect of electricity need, the demand of electricity always rising from time to time. On the other hand, the condition of electrical system still in need of improvement. Fundamental problema in electricity distribution system are quality, continuity and availibility of electricity services for consumers.To identify a feeder reliability, we use reliability index to represent reliability in a distribution

system. Reliability index that coomonly used are SAIDI (System Average Interruption Duration Index), SAIFI (System Average Interruption Frequency Index), Caidi (Costumer Average Interruption Duration Index), Asai (Average service availability index)

Failure modes and effect analysis (FMEA) is one of the method used to know reliability index of a system

With this journal, writer hopes to be able to give benefits for electricity company, especially PLN, to know about the reliability index of their system and how to improve from there. Furthermore, this journal should be able to help further students and reader to better understand distribution system and how to improve their reliability

2. Reliability and FMEA in 20 Kv distribution system

2.1. Reliability index in 20 KV distribution system

Reliability index is the scale used to measure level of reliabilty of a system. The basic measurement in reliability index to measure the reliability of the systems are "

- λ = average frequency of failure
- r = average of electricity shutdown time (hours/year)
- U = average of yearly electricty shutdown duration

Furthermore, reliability index used in system reliability measurement are as followed :

2.1.1 SAIFI (System Average Interruption Frequency Index)

SAIFI is the average amount of failure that happen at each costumers in one year.

$$SAIFI = (\Sigma (\lambda_i \times N_i))/\Sigma N \quad \text{failure/year*customer} \quad (1)$$

where :

SAIFI= (failure/year * customer)
λ = average index of failure per year (falure/year)
N_i = Sum of customers that experience blackout
N = Sum of all customers

2.1.2 SAIDI (System Average Interruption Duration Index)

SAIDI is the average time system disruption happens. SAIDI index could be achieved for the total of filure duration in one year divided with sum total of consumers. The equation for SAIDI is :

$$SAIDI = (\Sigma (U_i \times N_i))/\Sigma N \quad \text{hours/year*customer} \quad (2)$$

Dimana :

SAIDI = (hour/year * customer)
U = Average failure duration per year (hour/year)
N_i = Sum of consumers that experience blackout
N = Sum of all customers

2.1.3 CAIDI (Customer Average Interruption Duration Index)

CAIDI is average blackout duration of customers per disruption. CAIDI index resulted from dividing SAIDI with SAIFI index

$$CAIDI = SAIDI/SAIFI \quad \text{hours/customer*failure} \quad (3)$$

Where :

CAIDI = (hour/customer * failure)

2.2 Failure Modes and Effects Analysis (FMEA)

FMEA method used in evaluating reliability of distribution system, based on how a failure of a component in the system affect the failure on the whole system. Data needed to analyze reliability of a distribution system using FMEA are as follow

- Topology or configuration of 20Kv distribution feeder needed. Feeder configuration could be defined in branches, components that exist in the system could be represented in supply point and load point.
- Detail every load point with failure rate, repair time, and switching time
- Sum of effect on failure in every load pont.

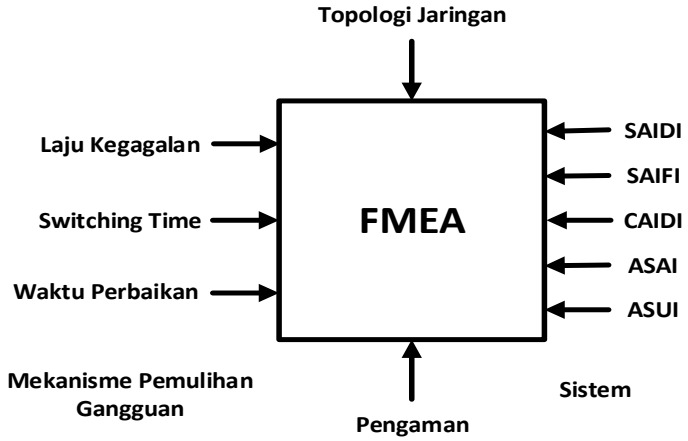

Figure 1. FMEA scheme

Several of load point index are as follow :

a. Failure rate for every load point is sum of failure rate in every component that affect the load pont
b. Average of disruption each year at every load point

3. Research Method

The analysis of data will be done with comparing the result of testing, the result of reliability index calculation using FMEA method in Ms.Excel, and the result from PT PLN Persero. Shown below the FMEA procedure flowchart for this research.

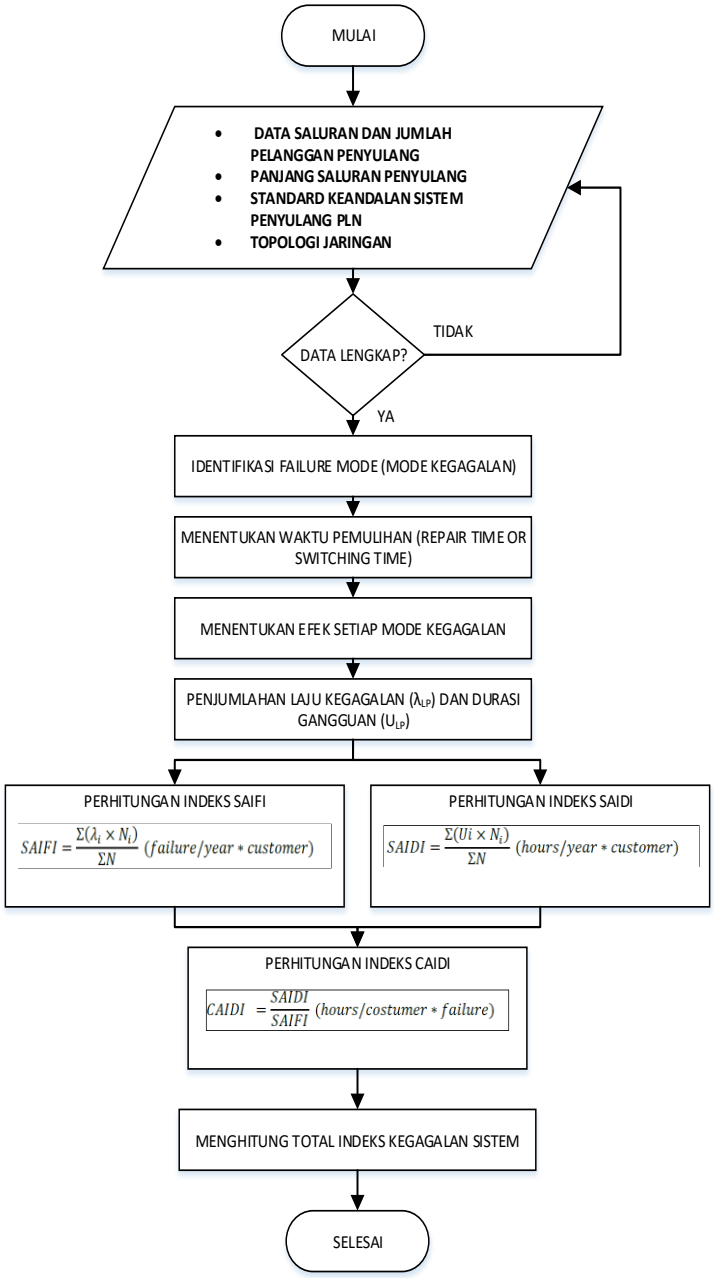

Figure 2. *FMEA* procedure flowchart

4. **Case study**

From **figure 10.** We could see that in PT. PLN (Persero) ULP Palopo Kota exit 13 feeder that being transmitted using four 150/20 kV stepdown transformers from palopo main substation. In transformer 1 with capacity of 20 MVA exist Mawa feeder, Merdeka feeder, Andi Djema feederm and Sawerigading feeder. In transformer 2 with capacity 20 MVA exist Lagaligo feeder, and Latuppa feeder. In transformer 3 with capacity of 20 MVA exist padang sappa feeder, walmas feeder, tandipau feederm and sabbang feeder. Transformer 4 with capacity of 30 MVA exist sampoddo feeder, bua feeder, and belopa feeder.

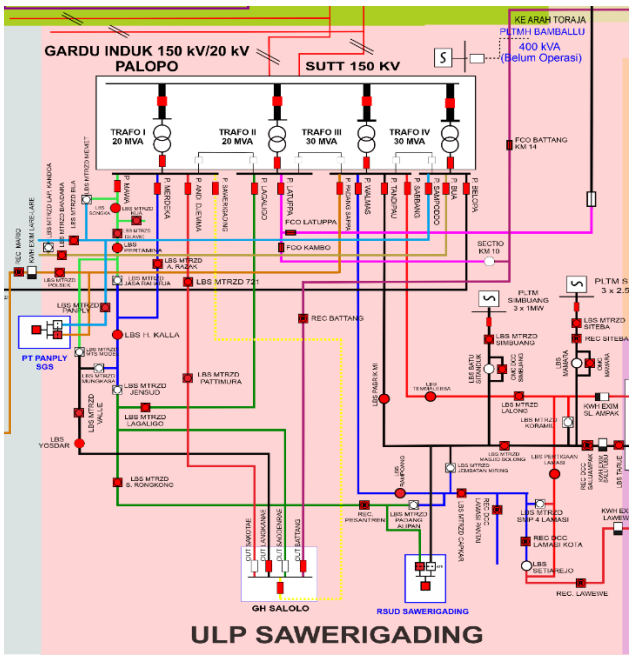

Figure 3. Single Line Diagram UP3 Palopo electricity system
(Source: PLN UP3 Palopo, 2020)

4.1 Latupa and Merdeka feeder topology data

To understand failur index of latuppa and merdeka feeder, all the data needed such as transformer capacity data, total of customer, and transformer load provided in table 1 and 3. Furthermore we also need the topology data of the network in length provided in table 2 and 4, shown below

Table 1. Network specification and customers in at latuppa feeder

LP	Transformator	Power (kVA)	Number of Users	Load kVA
1	610.KA	50	313	275.44
2	610.KB	25	156	137.28
3	610.KC	50	313	275.44
4	610.KD	50	156	137.28
5	610.BTS9	50	1	0.88
6	610.KG	50	26	22.88
7	610.KE	100	156	137.28
8	610.KF	50	1	0.88
9	610.KH	100	26	22.88
10	610.KN	50	1	0.88
11	610.MS	100	156	137.28
12	610.KO	25	39	34.32
13	610.KP	25	39	34.32
14	610.KQ	25	39	34.32
15	610.BTS10	25	1	0.88
16	610.KI	25	39	34.32
17	610.KJ	25	39	34.32
18	610.KK	50	78	68.64
19	610.KL	25	1	0.88
20	610.KM	25	39	34.32

Table 2. Length of latuppa feeder network

Conductor	L (km)	Conductor	L (km)
L1	0.5	**L14**	2.2
L2	0.8	**L15**	5.55
L3	0.95	**L16**	6.7
L4	1.35	**L17**	6.5
L5	1.95	**L18**	3.7
L6	3.6	**L19**	3.4
L7	2.9	**L20**	0.45
L8	3.45	**L21**	0.75
L9	3.9	**L22**	0.1
L10	1.6	**L23**	0.15
L11	1.15	**L24**	0.2
L12	1.85	**L25**	1.2
L13	1.15		

Table 3. Network specification and customers in at Merdeka feeder

LP	Transformator	Power (kVA)	Number of Users	Load kVA
1	610.FA	50	78	68.64
2	610.FB	100	156	137.28
3	610.BTS15	25	1	0.88
4	610.FC	50	78	68.64
5	610.FD	200	313	275.44
6	610.FE	160	111	97.68
7	610.FF	50	78	68.64
8	610.FG	250	391	344.08
9	610.AH	25	78	68.64
10	610.DH	160	250	220
11	610.DG	100	156	137.28
12	610.DF	200	313	275.44
13	610.AF	200	313	275.44
14	610.AG	160	250	220
15	610.FH	100	156	137.28
16	610.BTS16	25	39	34.32
17	610.FI	200	313	275.44
18	610.BTS17	25	39	34.32
19	610.FL	160	250	220
20	610.FM	100	156	137.28
21	610.FN	200	313	275.44
22	610.FO	25	39	34.32
23	610.FP	250	91	80.17777778
24	610.FS	50	211	185.2631579
25	610.FT	50	78	68.64
26	610.FU	250	391	344.08
27	610.FX	160	1	0.88
28	610.FY	160	250	220
29	610.FV	250	156	137.28

30	610.FW	250	391	344.08
31	610.MX	160	250	220
32	610.FZ	160	250	220
33	610.GA	200	313	275.44
34	610.GB	50	78	68.64
35	610.GG	160	166	146.08
36	610.GH	200	313	275.44
37	610.GI	200	313	275.44

Table 4. Length of Merdeka feeder network

Conductor	**L (km)**	**Conductor**	**L (km)**
L1	1.1	L26	0.2
L2	0.5	L27	0.15
L3	0.25	L28	0.2
L4	0.6	L29	0.05
L5	0.3	L30	0.1
L6	0.4	L31	0.05
L7	0.45	L32	0.15
L8	0.2	L33	0.15
L9	0.5	L34	0.2
L10	0.15	L35	0.15
L11	0.7	L36	0.15
L12	0.5	L37	0.2
L13	0.6	L38	0.05
L14	0.1	L39	0.2
L15	0.15	L40	0.15
L16	0.15	L41	0.15
L17	0.1	L42	0.15
L18	0.8	L43	0.3
L19	0.3	L44	0.1
L20	0.2	L45	0.1
L21	0.15	L46	0.15
L22	0.2	L47	0.15
L23	0.05	L48	0.15
L24	0.2	L49	0.15
L25	0.15		

4.2 Reliability index of Latuppa and Merdeka Network

From the datta of latuppa and merdeka feeder, we could calculate the reliability index for each load pont, shown below are the result of reliability index calculation in Merdeka and Latuppa Feeder (Table 5 and 7

Comparison between SAIFI, SAIDI and CAIDI index calculated using FMEA and the data gained from PLN palopo kota also shown in tabel 6 and 8

Table 5. Reliability index calculation result in latuppa feeder

LP	λ	U	N	SAIFI	SAIDI	CAIDI	ASAI	ASUI
LP1	11.267	18.2685	313	2.1782	3.5318	0.6167	0.9979	0.0021
LP2	11.267	18.2685	156	1.0856	1.7603	0.6167	0.9979	0.0021
LP3	11.267	18.2685	313	2.1782	3.5318	0.6167	0.9979	0.0021
LP4	11.267	18.2685	156	1.0856	1.7603	0.6167	0.9979	0.0021
LP5	11.267	18.2685	1	0.0070	0.0113	0.6167	0.9979	0.0021
LP6	11.267	18.2685	26	0.1809	0.2934	0.6167	0.9979	0.0021
LP7	11.267	18.2685	156	1.0856	1.7603	0.6167	0.9979	0.0021
LP8	11.267	18.2685	1	0.0070	0.0113	0.6167	0.9979	0.0021
LP9	11.267	18.2685	26	0.1809	0.2934	0.6167	0.9979	0.0021
LP10	11.242	16.3085	1	0.0069	0.0101	0.6893	0.9981	0.0019
LP11	11.242	16.3085	156	1.0832	1.5714	0.6893	0.9981	0.0019
LP12	11.242	16.3085	39	0.2708	0.3929	0.6893	0.9981	0.0019
LP13	11.242	16.3085	39	0.2708	0.3929	0.6893	0.9981	0.0019
LP14	11.242	16.3085	39	0.2708	0.3929	0.6893	0.9981	0.0019
LP15	11.267	18.2685	1	0.0070	0.0113	0.6167	0.9979	0.0021
LP16	11.242	3.6260	39	0.2708	0.0873	3.1004	0.9996	0.0004
LP17	11.242	3.6260	39	0.2708	0.0873	3.1004	0.9996	0.0004
LP18	11.242	3.6260	78	0.5416	0.1747	3.1004	0.9996	0.0004
LP19	11.242	3.6260	1	0.0069	0.0022	3.1004	0.9996	0.0004
LP20	11.242	3.6260	39	0.2708	0.0873	3.1004	0.9996	0.0004
TOTAL			1619					
	SAIFI			11.26				
		SAIDI			16.16			
			CAIDI			1.436		
				ASAI			0.259	
					ASUI			0.741

Table 6. Selisih Perbandingan FMEA dengan Data PLN Penyulang Latuppa

Indeks	FMEA	Data PLN	Selisih
SAIFI (gagal/plg.th)	11,26	3,37	7,89 (70,07%)
SAIDI (jam/plg.th)	16,16	2,38	13,78 (85,27%)
CAIDI (jam/plg.gagal)	1,436	1,41	0,026 (1,81%)

Table 7. Hasil Perhitungan Keandalan Penyulang Merdeka

LP	λ	U	N	SAIFI	SAIDI	CAIDI	ASAI	ASUI
LP1	1.958	4.3969	78	0.0214	0.0482	0.4453	0.9995	0.0005
LP2	1.958	4.3969	156	0.0429	0.0963	0.4453	0.9995	0.0005
LP3	2.028	4.6769	1	0.0003	0.0007	0.4336	0.9995	0.0005
LP4	2.028	4.6769	78	0.0222	0.0512	0.4336	0.9995	0.0005
LP5	1.958	4.3969	313	0.0860	0.1932	0.4453	0.9995	0.0005
LP6	1.958	4.3969	111	0.0305	0.0685	0.4453	0.9995	0.0005
LP7	1.958	4.3969	78	0.0214	0.0482	0.4453	0.9995	0.0005
LP8	1.958	4.3969	391	0.1075	0.2414	0.4453	0.9995	0.0005
LP9	2.068	5.6209	78	0.0226	0.0616	0.3679	0.9994	0.0006
LP10	2.068	5.6209	250	0.0726	0.1973	0.3679	0.9994	0.0006
LP11	2.068	5.6209	156	0.0453	0.1231	0.3679	0.9994	0.0006
LP12	2.068	5.6209	313	0.0909	0.2470	0.3679	0.9994	0.0006
LP13	2.068	5.6209	313	0.0909	0.2470	0.3679	0.9994	0.0006
LP14	2.068	5.6209	250	0.0726	0.1973	0.3679	0.9994	0.0006
LP15	1.958	4.3969	156	0.0429	0.0963	0.4453	0.9995	0.0005
LP16	1.958	4.3969	39	0.0107	0.0241	0.4453	0.9995	0.0005
LP17	1.958	4.3969	313	0.0860	0.1932	0.4453	0.9995	0.0005
LP18	1.823	1.4074	39	0.0100	0.0077	1.2953	0.9998	0.0002
LP19	1.823	1.4074	250	0.0640	0.0494	1.2953	0.9998	0.0002
LP20	1.823	1.4074	156	0.0399	0.0308	1.2953	0.9998	0.0002
LP21	1.823	1.4074	313	0.0801	0.0618	1.2953	0.9998	0.0002
LP22	1.823	1.4074	39	0.0100	0.0077	1.2953	0.9998	0.0002
LP23	1.823	1.4074	91	0.0233	0.0180	1.2953	0.9998	0.0002
LP24	1.853	2.6324	211	0.0548	0.0778	0.7039	0.9997	0.0003
LP25	1.853	2.6324	78	0.0203	0.0288	0.7039	0.9997	0.0003
LP26	1.853	2.6324	391	0.1017	0.1445	0.7039	0.9997	0.0003
LP27	1.853	2.6324	1	0.0003	0.0004	0.7039	0.9997	0.0003
LP28	1.853	2.6324	250	0.0650	0.0924	0.7039	0.9997	0.0003
LP29	1.853	2.6324	156	0.0406	0.0577	0.7039	0.9997	0.0003
LP30	1.853	2.6324	391	0.1017	0.1445	0.7039	0.9997	0.0003
LP31	1.853	2.6324	250	0.0650	0.0924	0.7039	0.9997	0.0003
LP32	1.853	2.6324	250	0.0650	0.0924	0.7039	0.9997	0.0003
LP33	1.853	2.6324	313	0.0814	0.1157	0.7039	0.9997	0.0003
LP34	1.853	2.6324	78	0.0203	0.0288	0.7039	0.9997	0.0003
LP35	1.853	2.6324	166	0.0432	0.0614	0.7039	0.9997	0.0003
LP36	1.853	2.6324	313	0.0814	0.1157	0.7039	0.9997	0.0003
LP37	1.853	2.6324	313	0.0814	0.1157	0.7039	0.9997	0.0003
TOTAL			7123					
	SAIFI			1.916				
		SAIDI			3.478			
			CAIDI			1.815		
				ASAI			0.48	
					ASUI			0.52

Table 8. Selisih Perbandingan FMEA dengan Data PLN Penyulang Merdeka

Index	FMEA	PLN's Data	Gap
SAIFI (gagal/plg.th)	1,916	4,12	2,204 (53,49%)
SAIDI (jam/plg.th)	3,478	1,39	2,088 (60,03%)
CAIDI (jam/plg.gagal)	1,815	2,95	1,135 (38,47%)

There are significant difference between reliabilitiy index calculated from FMEA and actual data from PLN, this difference could be caused by:

- PLN data uses actual in field data that could be effected by the situation of environment and weather. Also PLN uses historical data for their reliability index calculation.
- FMEA method did not count weather factor and deliberate blackout from PLN.
- At the moment ULP Palopo Kota have done more corrective maintenance to handle disruption that happen and only a little of preventive maintenance such as routine foliage inspection at each network to prevent foliage to touch and disrupt the network.
- Manouver that PLN done is based by the load amount being loeaded where it is depend on time

Because of the point abve the reliability index is far different from the FMEA method calculation that is a predictive calculation

5. Conclusion

From the calculation and analysis that have been done, we could take conclusion as written below :

- The result of reliability index calculation using FMEA method in Latuppa feeder are :
  - SAIFI : 8,91 gagal/pelanggan.tahun
  - SAIDI : 18,33 jam/pelanggan.tahun
- The result of reliability index calculation using FMEA method in Merdeka feeder are :
  - SAIFI : 1,916 gagal/pelanggan.tahun
  - SAIDI : 3,478 jam/pelanggan.tahun

Frequency of failure at the network results in high frequency of failure in the system compared with frequency of failure in the equipment such as transformer, switch and CB so that it affect the SAIFI index. On the other hand SAIDI index will also becom larger because of the failure duration that happen. To compensate from the big number in SAIFI and SAIDI index, there will be need for fuse component and sectionalizer so that the system could perform reliably

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