Fault Analysis of Power Distribution Network Using FTA and FMEA: A Study at PT PLN

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ABSTRACT

PT. PLN is a supplier of electrical energy in Indonesia which plays an important role in providing sufficient electricity for daily activities, industry and other sectors. UPDK Kapuas is a power plant in Pontianak City. Based on SAIDI and SAIFI data, the duration and frequency of blackouts in 2021 is 14.85 hours per customer per year and 14.5 times per customer per year, while in 2022 it will be 16.85 hours per customer per year and 17.16 times per customer. This has increased every year. Then the average loss value in 2022 will be 11% and the average Energy Not Supplied (ENS) value will be 26,265 kWh/month. Based on the Fault Tree Analysis method, there are 25 causes of network disruption from internal and external. Of the 25 causes of network disruption, it was reduced based on the minimum Cut Set results to 5, namely, damage caused by natural disturbances, animals, humans, installation errors, and electrical component disturbances. The highest RPN value result was caused by electrical cables amounting to 11638 which needed to be a priority repair by UPDK Kapuas. Recommendations for improvement include carrying out routine maintenance and maintenance of the network to prevent damage and adding Thermovision tools to identify and detect network damage more quickly and precisely .

1. INTRODUCTION

Electricity is one of the strategic commodities in the Indonesian economy. Apart from being widely used by society, especially for lighting purposes, electricity is also one of the main energy sources for the industrial sector. The provision of electric power can be divided into three processes of delivering electric power, namely generation, transmission and distribution which can be considered as the production or manufacture, transportation and retail sale of electric power (Arismunandar, 1995). Electricity production at PLN in electricity distribution is an important aspect in measuring the quality of PLN services so that customer satisfaction remains high. The archive data from the Pontianak Customer Implementation Unit (UP3) explains the total sales productivity in 2021 to 2023 which is shown in the following table.

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Table 1. PLN Electricity Reliability Parameters for Pontianak City Area

Aspect	Unit	2021	2022
Contracted Power	VA	68,903,612	72,265,912
Electricity Production	GWh	9,131,742	9,679,916
Sale	kWh	123,868,743.82	126,274,048.87

Source: Pontianak Customer Implementation Unit (UP3).

Disruption to the distribution network can be caused by contact with trees and strikes in areas outside the city (Senen, 2019). There are two problems at UPDK Kapuas, namely, power outages caused by disruption of the electricity distribution network and losses caused by theft of electrical energy. In this research the author focuses on power outages caused by disruption of the electricity distribution network. Electrical energy sent by the substation cannot reach customers because of damage to the distribution network which converts electrical energy into heat energy. Apart from that, power outages can also be caused by damage to the distribution network. If there is a disruption to the electricity distribution network or a blackout, it is possible that PLN's electricity income will decrease because customers do not consume electricity (UPDK Kapuas, 2022) .

The electricity sold by PLN Pontianak, especially UPDK Kapuas, has value which is not in accordance with the electricity produced. This difference is caused by two things, namely *Energy Not Supplied* (ENS) and electricity loss. ENS is the amount of electricity that cannot be distributed or channeled by the company due to internal disturbance factors and external disturbance factors . Another electricity reliability is the value of electricity loss, which shows PLN's efficiency in distributing electricity. The lower the loss value, the more efficient PLN is in distributing electricity. Electricity loss and power not being distributed can be caused by internal disturbances or external disturbances. In the distribution of electric power, PLN often experiences internal disturbances from PLN such as disturbances caused by the system itself, for example short circuit disturbances, damage to equipment, switching insulation failures, damage to generators and so on. Meanwhile, externally caused by nature or outside the system, such as broken lines/cables due to wind, storms, lightning, trees, kites and so on (Pabla, 1994).

Table 2. Power Outage Parameters for Pontianak City Area

Index	Unit	2021	2022
Outage Duration	Hours/Customers	14.85	16.85
Outage Frequency	Times/Customers	14.55	17,16

Source: Pontianak Customer Implementation Unit (UP3).

When the duration and frequency of power outages reaches a number that exceeds the duration of 10 hours per customer per year and a frequency of 10 times per customer per year, the limit values set by UP3 Pontianak, then there are problems in the electricity distribution system that cannot be ignored by PLN which can be caused by by a power outage.

The impact of network disruption due to power outages felt by PLN, especially UPDK Kapuas, was in the form of lost opportunities to sell electricity and a worsening of PLN's image.

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Meanwhile, the impact felt by the community is in the form of 5 power outages and the risk of damage to electronic equipment. In an effort to overcome this problem, this research uses the Fault Tree Analysis (FTA) method first to describe the causes of power outages, then to assess the priority scale for repairs, the Failure Mode and Effect Analysis (FMEA) method is used.

2. RESEARCH METHODS

2.1 Time and Place of Research

Research and data collection was carried out at the PLN Generation Control Implementation Unit (UPDK) Kapuas Pontianak at the Sei Raya PLTD plant from March 2023 to May 2023 .

2.2 Object of research

The object of this research is the root cause of disturbances in the electricity transmission distribution network and priority repairs to black outs due to disturbances in the electricity distribution network. This research is focused on reducing the number of network disruptions and improving electricity distribution services.

2.3 Research methods

This research uses the *Fault Tree Analysis (FTA)* method to describe the causes of power outages, then to assess the priority scale for repairs, the *Failure Mode and Effect Analysis* (FMEA) method is used.

3 THEORETICAL BASIS

3.1 Electricity Distribution System k

The distribution system is an electricity flow that produces electrical energy from generators to consumers. The electricity production unit produces 11 kV and 24 KV electricity. Then the voltage is increased to 500 kV via a high voltage transformer and distributed via transmission. The aim of increasing the voltage to 500 kV is to reduce the amount of power lost in the transmission line. Electrical power loss is proportional to the square of the current passing through it. With the same power, the value of the current flowing is smaller if the voltage value is increased, so that the power loss is also smaller according to (Pabla, 1994)

3.2 Network Disruption

Disturbances in the distribution system are abnormal system reliability that causes short circuits and open circuits. A disturbance in the electrical system causes the supply line relay to function and open the substation circuit breaker, cutting off electricity (Wendy, 1978). Disturbances in distribution networks occur more frequently in overhead lines (SUTM) which generally do not use insulation compared to distribution lines with ground cables (SKTM), because they use wrapping insulation.

3.3 Factors affecting Distribution System Reliability

Some components that must be considered to ensure the distribution system operates correctly are as follows, (Pabla, 1994):

1. Temperature

   The magnitude of the load current is limited by temperature, meaning the load for this type of system element is determined by temperature rather than mechanical factors. These limits vary 12 depending on the load configuration and weather, so limit areas are established to control the load under various conditions

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2. Voltage Drop
   A term used to describe the difference between the voltage at the sending and receiving ends of electricity. Load and work factors, impedance, line ingress. affects the alternating current line voltage.
3. Overvoltage
   Components must be able to handle not only voltage losses but also voltage spikes caused by the system or external sources.
4. Overload When a Disturbance Occurs
   Fault current entering the system will cause the system to experience an overload state, which results in the system becoming abnormal. If this is allowed to continue, it may harm system equipment.
5. Loss of Energy Source
   A disturbance in the generating unit or a short circuit in the network causes the loss of generation. This causes the CB and relay to work and the network is disconnected from the generator .

3.4 *Energy Not Supplied* (ENS)

According to Erhaneli (2016), the electric power distribution system is part of the electrical equipment system which includes a large power source (bulking power source) and customer contact equipment (customer contact equipment). In the 13 electricity distribution network, the system is divided into two, namely primary distribution (Medium Voltage Distribution Network) and secondary distribution (Low Voltage Distribution Network). The primary distribution system operating voltage is usually 6 kV or 20 kV, while the secondary distribution system voltage is 380 Volts or 220 Volts. ENS (Energy Not Supplied) is a reliability index that shows the amount of voltage provided.

3.5 *Failure Mode and Effect Analysis* (FMEA)

Failure Mode and Effect Analysis (FMEA) is an inductive analysis method used to find the most likely product and/or process defects by identifying opportunities, causes, effects, and improvement priorities based on the level of importance of the failure. Inductive analysis begins by identifying the causes of damage and how damage can occur (Stamatis, 1995) . The steps to run FMEA are, (Company, 2011).

3.6 *Fault Tree Analysis* (FTA)

Fault Tree Analysis (FTA) is a deductive analysis method for identifying damage or failure in the system by presenting alternative events in a structured diagram. Deductive analysis can be carried out on complex systems (Blanchard, 2004). Fault Tree Analysis (FTA) is used to look at the "Top - Down Approach", so that identifying failure modes analysis starts from the top level system and continues downwards .

4 RESULTS AND DISCUSSION

The following is recapitulation data on disturbance complaints per type of disturbance in 2022 in Pontianak City, data obtained from UP3 Pontianak.

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Month	Unplanned Outages			Planned Outages	Blackouts Due to Natural Disasters
	Distribution Substation	Low Voltage Networks	Electrical Power Connection	Maintenance	
January	0	6	21	2	0
February	0	11	36	2	0
March	0	38	96	5	2
April	0	116	115	1	0
May	0	73	139	3	0
June	0	79	133	1	0
July	0	117	123	0	0
August	2	165	249	0	6
September	0	143	216	2	1
October	0	176	201	0	1
November	0	149	119	0	0
December	0	127	160	0	0
Total	2	1200	1608	16	10

Data Which obtained from archives and field observations carried out at UP3 Pontianak And UPDK Kapuas Which Where as manager network distribution electricity. *Fault* Results*The tree* of electricity distribution network disruptions in the Pontianak city area is shown in the image below.

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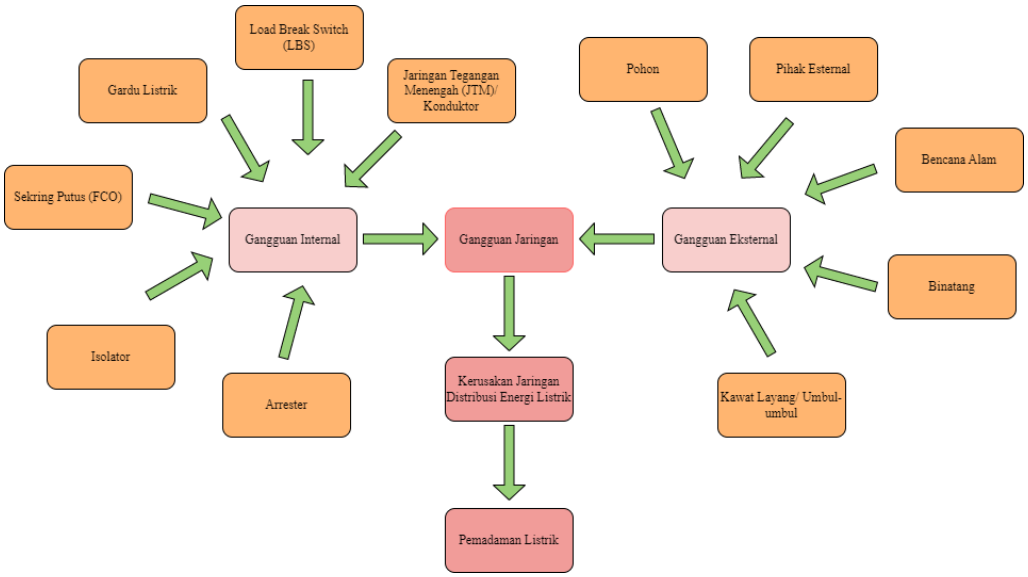

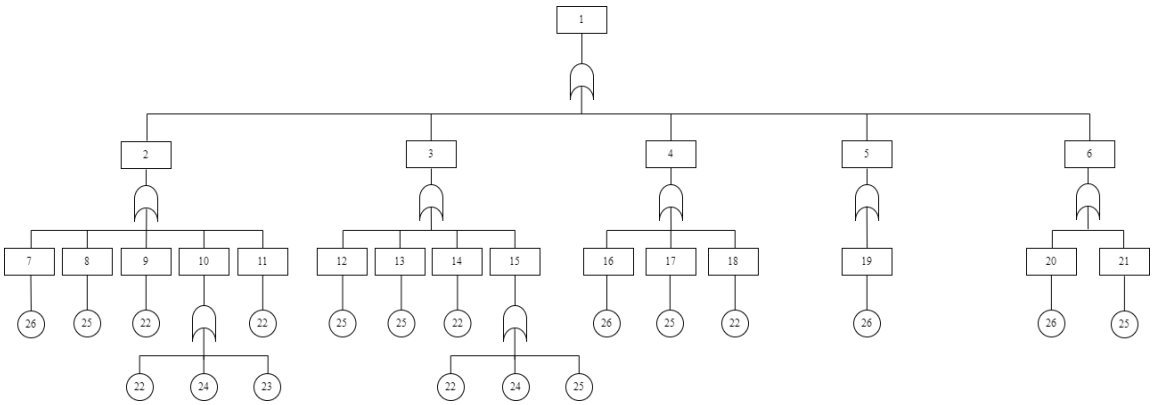

The results of the analysis of causal factors and impacts are obtained from calculation *Cut Set* Which is *basic events* from damage disturbance network as well asThe impact caused is based on the results of interviews with UPDK Kapuas employees Which Where as damage analyzer consequence network disruption.

Factor Reason And Impact Incurred Disturbance Network

Factor Reason	**Reason It happened Disturbance**	**Impact Which Incurred**
Environment	Animal	Tissue disorders caused by animals like bird, bats, snakes, slow lorises, squirrel, etc Which about And hang on cable, The animal carries out activities on the cable electricity Which cause stuck And dead in on cable electricity make part sender

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		voltage (cables) in the network system is disrupted until blackout.
	Natural	Disturbance network natural like wind tight, storms, lightning, heavy rain, landslides cause damage cable And pole electricity, damage antidote lightning, and damage connector.
Material Material Component	Conditions and Age Material	Disturbances in component materials usually caused Because material Which used Already long, so it is easily porous, brittle, broken, worn out, And broken quality component Which used in distribution electricity No Good so that distribution electricity become disturbed And give rise to disturbance.
Human	Failure installation installation (Internal Company)	Failure installation installation caused by installation network electricity Which done Nofollow procedure Which determined, or installation component Which No connected withstrong One The same other Which can with easy damage electricity distribution network.
	ActionsMan	Disturbances caused by human activities often cause damage on network electricity distribution. Activities such as flying kites overpasses, banners, theft of electricity meters and excavation channel PDAM can cause damage network distribution. However No only Thatjust, disturbance can happen consequence party to 3 like error disconnecting the wifi cable from the power cable PLN.

Risk of power outages caused by distribution network disruption In electricity, there are five *basic* failure events obtained from *the Fault Tree cut set Analysis,* Then reduced become three so that can focus to damage Whichcaused. This risk is a risk that originates from internal and external aspects external UPDK Kapuas. The data obtained comes from field observations, interview as well as files data PLN UPDK Kapuas And UP3 Pontianak. As for analysisreason

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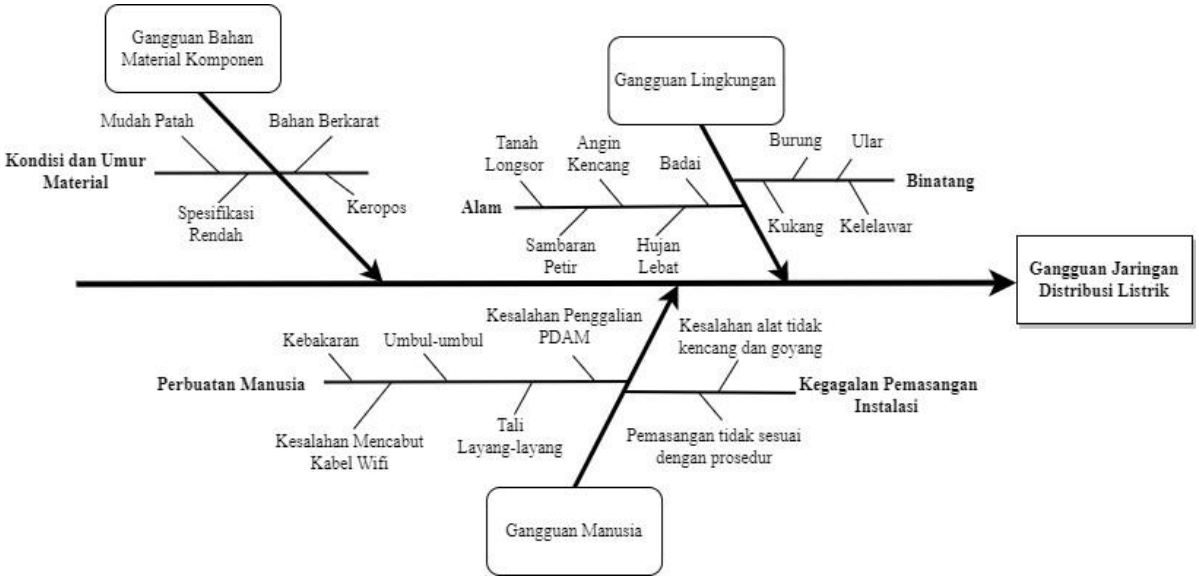
from blackout electricity Which caused by disturbance network distribution electricity with diagrams *fishbone* shown in the following image.



Amount calculation RPN Which originate from results determination minimum *Cut Set* method *Faults Tree Analysis* (FTA) is in attachment 4, namely data obtained from the questionnaireshared to 5 person worker in field disturbance network distribution electricity or TeamOperation Order Genre Electricity (OPAL) UPDK Kapuas. Following is the total RPN calculation results obtained from the questionnaire used For determine scale improvement priorities network disruption.

Damaged Components and Risk of Interference	**Consequences of Damage**	**Number of Scales**			**RPN Value Results**
		S	**O**	**D**	
Insulator	Too high a voltage makes the insulator get hot until it breaks	20	22	20	8800
Electrical Safety Fuse	Excessive electrical load passes through the fuse and causes the fuse to break	16	12	13	2496
Grounding	The lightning strike was too strong resulting in an explosion	18	16	13	3744
Generator Relay	The relay contacts are burnt and weak so they don't touch well	14	10	11	1540
Voltage Jumper	The jumper is too loose and breaks	16	14	10	2240

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Load Break Switch	The current shift setting does not work	10	14	15	2100
Power house	There was a partial blackout	21	21	21	9261
Power pole	Electrical poles collapsed due to natural disturbances	21	22	21	9702
Power cable	Power lines are broken by trees, kites, wind, and so on	22	23	23	11638
Cutting off electric current/power (PMT)	Fuse is not installed properly (Not Tight)	15	14	16	3360
Electrical circuit separator (PMS)	Fuse is not installed properly (Not Tight)	14	13	14	2548
Connectors	The connector is unstable and there are obstacles	10	14	11	1540
Transformer Jumper	Transformer jumper broken	12	13	15	2340
Mini Circuit Breakers (MCB)	The MCB was damaged and caught fire	13	16	18	3744
Arrester	The insulator does not work making the conductor unable to withstand the voltage	15	14	15	3150
Normalizing Long-Term Disorders	Lost revenue due to long network disruptions and inexperienced operators	23	19	20	8740
Very High Electrical Losses and Not Optimal Analysis	Plants that are far from switchgear make the load on the transformer low and the accuracy of customer meters is low and inaccurate.	19	17	19	6137
Length of Time in Analysis	Inexperienced operator less precise and not optimal as well	17	23	20	7820
Kite wireand pennants regarding the network electricity	Many children play kitesfly using wire as a result wire rub together withpower cable and make it break cable until blackout	22	24	21	11088

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Failure and Weak System Network Protection Electricity	*Wiring* installation errors as wellrelays Which separated And No workswhich can be caused by factors natural	20	20	20	8000

It can be seen based on Table 4.9 that there are 20 components that are damaged and at risk network disruption that could be detrimental to UPDK Kapuas based on impact (*Severit*), frequency (*Occurrence*), and detection (*Detection*) to obtain a value priority risk (RPN) as repair in handle repair disturbance networkelectricity distribution.

5 CONCLUSION

There were 15 component failures and 5 internal errors which were the main causes of network disruption. The most damage to components is cables and electrical substations caused by kite wires and trees hitting these components. Internal errors from UPDK Kapuas such as long normalization of disturbances, very high electrical losses and non-optimal analysis, the length of time in analyzing the causes of network disturbances is less than optimal, failure and weakness of the electrical network protection system. Operational risks that occur due to energy losses due to technical and non-technical problems in the distribution of electrical energy.

Fault Tree Analysis method , there are 2 5 causes of network disruption from internal and external. From 2 5 causes of network disruption, the minimum *Cut Set result was reduced* to 5, namely, damage caused by natural disturbances, animals, humans, installation errors, and electrical component disturbances. *The fishbone* diagram is reduced to three causes, namely human disturbance, the environment and component materials. Repairing and preventing disruption to the electricity distribution network can start from the cables and electrical substations. UPDK Kapuas can pay attention to priority improvements in order to reduce the number of power outages in Pontianak City and increase public satisfaction as customers.

Recommendations for repairs due to damage caused by carrying out routine and regular *maintenance* of distribution network equipment to prevent damage, changing electricity distribution lines from overhead lines to underground lines, creating maintenance programs, management programs or collecting performance data from power transformers on a regular basis, planning programs distribution of electricity to 79 customers, adding thermovision equipment to identify and detect damage to the distribution network more quickly and precisely, installation of the network must be in accordance with established procedures, as well as installation of capacitors in large spaces, namely equipment to increase *the power factor* which will affect the amount of current which is supplied thereby reducing power losses caused by network damage .

6 DECLARATION OF COMPETING INTEREST

We declare that we have no conflict of interest.

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