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Analysis of Distribution Network Disruptions Using Fault Tree Analysis: A Case Study of the Bandung Feeder at PT. PLN Bengkalis

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ABSTRACT

The electricity distribution network plays an important role in distributing electrical energy from substations to customers. At the Bandung PT. PLN (Persero) ULP Bengkalis feeder, there are still disruptions that cause blackouts and reduce service quality. This study aims to analyze the causes of disruptions using the Fault Tree Analysis (FTA) method to identify the dominant factors and root causes. The methods used include literature studies, observations, interviews, and data collection on disruptions from January 2025 to Desember 2025 This study was motivated by the limitations of previous studies, which generally used Fault Tree Analysis (FTA) only in a descriptive manner without a quantitative approach and did not consider the influence of local factors on power distribution network outages. Therefore, this study aims to develop a semi-quantitative, probability-based FTA approach and to examine the characteristics of outages in the Bengkalis region. The scientific contribution of this study lies in the integration of probabilistic analysis into FTA and the strengthening of risk-based recommendations to improve the reliability of the electrical distribution system. Animals such as birds, squirrels, or other creatures can cause disruptions by coming into contact with or bridging conductors, which can potentially cause short circuits. The high frequency of interactions between electrical networks and their surroundings, combined with a lack of monitoring and protection of the networks, makes these two factors more significant than other causes. When comparing internal and external disruptions, it is evident that external disruptions account for a larger proportion—approximately 59% of total disruptions—while internal disruptions account for about 41%. This confirms that the reliability of the distribution system in the study area is more heavily influenced by external factors than by the technical condition of the equipment itself.

Keywords: *Disturbance; Distribution Network; Fault Tree Analisys*

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1. INTRODUCTION

Electricity is an essential requirement for supporting various activities in modern society, including in the household, industrial, educational, and public service sectors. Therefore, the continuity and reliability of the electricity distribution system are critical factors in maintaining the stability of social and economic activities. As the component directly connected to customers, the electricity distribution system plays a vital role in ensuring that electricity is delivered continuously and reliably [1], [2].

However, in practice, power distribution networks frequently experience disruptions that can lead to power outages. These disruptions can stem from various factors, such as equipment failure, environmental conditions, natural phenomena, and human activities in the vicinity of the network [3], [4]. Several studies indicate that external disturbances such as fallen trees, animals, and community activities (e.g., kites and third-party work) are significant contributors to distribution network disruptions [5], [6]. This suggests that the reliability of the distribution system is influenced not only by technical factors but also by social and environmental factors.

A widely used analytical method for systematically identifying the causes of failures is Fault Tree Analysis (FTA). FTA is a deductive analysis method capable of logically and structurally depicting the cause-and-effect relationships of a system failure [7], [8]. In several recent studies, FTA has proven effective in determining the root causes of failures and identifying the dominant factors affecting the reliability of electrical distribution systems [9], [10].

Research on the application of FTA in electrical distribution networks within PT. PLN (Persero) has been conducted in various regions. The results of this research indicate that external factors, such as human and environmental activities, are often the primary cause of faults compared to internal equipment factors [11], [12]. However, most of this research remains general in nature and has not specifically examined the characteristics of faults on specific feeder lines under varying local conditions.

PT. PLN (Persero) ULP Bengkalis operates several distribution lines, one of which is the Bandung Line, which supplies electricity to a specific area. Based on data on outages, this line continues to experience significant disruptions, particularly those caused by external factors such as community activities and the surrounding environment. These conditions indicate unique outage characteristics compared to other regions.

Consequently, this study was conducted to analyze the causes of power distribution network outages on the Bandung Feeder using the Fault Tree Analysis (FTA) method. This study is expected to provide a more specific understanding of the factors causing the outages and to generate appropriate recommendations aimed at improving the reliability of the power distribution system in the region.

2. REASEARCH METHOD

In this study, the Fault Tree Analysis (FTA) method is not only used to identify the cause-and-effect relationships of failures but can also be developed into a probabilistic analysis to measure the likelihood of a failure occurring. Probability is measured using an event frequency approach (historical data), in which the probability of each basic event is calculated based on the number of occurrences relative to the total number of failures that occurred during the observation period.

Mathematically, the probability of a basic event can be expressed as:

$$P(A) = \frac{f_A}{\sum f} \tag{1}$$

where $P(A)$ is the probability of event A, f_A is the frequency of event A, dan $\sum f$ is the total of all disruption events. Based on the 2025 disruption data, the total number of disruptions that occurred was 22 (9 internal and 13 external). Thus, the probability of each disruption category can be calculated as follows:

a) Probability of internal failure = 9/22 = 0.409
b) Probability of external failure = 13/22 = 0.591

For a more detailed analysis, the probability of each basic event can also be calculated, for example:

a) JTM component (I-1): 4/22 = 0.182
b) Transformer (I-3): 5/22 = 0.227
c) Third-party work/animals (E-3): 9/22 = 0.409
d) Trees (E-1): 3/22 = 0.136
e) Natural disasters (E-2): 2/22 = 0.091

These results indicate that the failure with the highest probability stems from external factors, specifically the actions of other parties or animals (E-3), which is the most dominant basic event in the fault tree structure.

However, in this study, the approach used is still semi-quantitative, as probabilities are calculated based on the frequency of events without considering the failure rate or advanced statistical distributions.

Thus, the probability analysis in the FTA provides an indication of the likelihood of a failure occurring and helps in determining maintenance priorities. The higher the probability value of an event, the greater its contribution to system failures, making it a primary focus in maintenance and risk mitigation strategies.

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2.1 Research Location

This research was conducted in the Bengkalis PLN ULP Network Service Unit area from October 24 to November 24, 2025, to determine the condition and situation of the electricity distribution system. Bengkalis PLN ULP Network Service Unit.

2.2 Data Collection

Data yang digunakan dalam penelitian ini adalah data gangguan jaringan distribusi listrik di Penyulang Bandung PT. PLN (Persero) ULP Bengkalis selama periode Januari hingga Desember 2025. Data tersebut disusun dengan resolusi waktu bulanan, di mana setiap kejadian gangguan direkapitulasi berdasarkan jumlah kejadian pada masing-masing bulan. Penggunaan resolusi waktu bulanan dinilai efektif untuk mengidentifikasi pola dan tren gangguan dalam sistem distribusi listrik, serta banyak digunakan dalam analisis keandalan sistem tenaga listrik [13], [14].

In addition to being categorized by time, the data is also classified by type of outage: internal outages and external outages. Internal outages are those originating from within the distribution system, such as damage to medium-voltage network (MVN) components, equipment, transformers, and supporting structures like utility poles. Meanwhile, external faults are those caused by factors outside the system, such as tree-related faults, natural disasters, animal activity, and human activities such as third-party work and foreign objects (e.g., kites) coming into contact with the power grid [4], [5].

This classification of disturbances into internal and external categories is intended to facilitate the identification of disturbance sources and the determination of appropriate mitigation strategies. According to several studies, external disturbances are often the dominant cause of disturbances in electrical distribution systems due to the high level of interaction between the grid and the surrounding environment [9], [12].

Each category of failure in this study was then broken down into subcategories (I-1, I-2, I-3, I-4 for internal failures and E-1, E-2, E-3, E-4 for external failures). This grouping was performed to support analysis using the Fault Tree Analysis (FTA) method, which requires the systematic identification of basic events so that cause-and-effect relationships can be clearly mapped [15]. With this approach, the dominant factors causing failures can be identified more accurately and in a structured manner.

2.3 Data Processing

The data processing carried out in this final project research is FTA (Fault Tree Analysis). The FTA stage is used to determine the events or combinations of basic events that cause damage to the distribution network. At this stage, the root causes that most significantly affect network disruptions in electricity distribution will be further analyzed using FTA (Fault Tree Analysis). FTA uses deductive analysis to find the cause and effect relationships of an event in the system and then systematically involves all possible events and errors that can cause damage (Undesired Event).

2.4 Research Flowchart

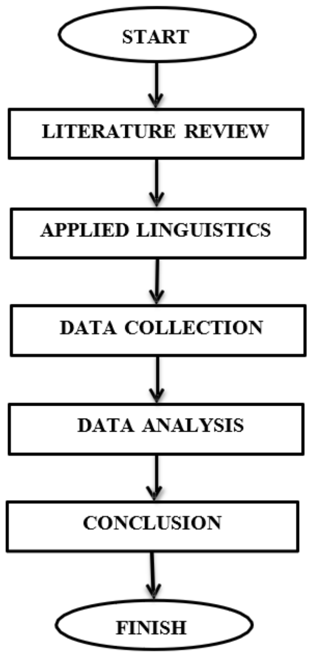

Figure 1. Research Flowchart

This research procedure first conducted a literature study by collecting data from several source books, then analyzed the causes of network disruptions in electricity distribution. The data processed was experimental data using the Fault Tree Analysis (FTA) method.

3. RESULTS AND DISCUSSION

3.1. Data Collection

The data collected was sourced from PLN's monthly reports; data processing was performed using Microsoft Excel via the FTA method.

Table 1. The Performa of Temporary Internal Network Disruptions in Electricity Distribution

Month	INTERNAL				EXTERNAL			
Category	I-1	I-2	I-3	I-4	E-1	E-2	E-3	E-4
January 2025	-	-	-	-	-	-	-	-
February 2025	2	-	-	-	-	-	3	-
March 2025	1	-	1	-	1	-	2	-
April 2025	-	-	2	-	1	2	2	-
Mai 2025	-	-	-	-	-	-	-	-
June 2025	-	-	-	-	-	-	-	-
July 2025	-	-	-	-	-	-	-	-
August 2025	-	-	-	-	-	-	-	-
September 2025	-	-	-	-	-	-	-	-
Oktober 2025	-	-	-	-	-	-	-	-
November 2025	1	-	2	-	-	-	2	-
Desember 2025	-	-	-	-	-	-	-	-
Total	4	-	5	-	3	2	9	-

Table 1 shows that the average number of permanent network outages occurring within PT. PLN ULP Bengkalis was caused by JTM components, totaling 5 outages from January 2025 to December 2025. Meanwhile, the average number of permanent network outages occurring externally to PT. PLN ULP Bengkalis was caused by natural disasters, totaling 9 outages.

Based on the 2025 electricity distribution network outage table, it is evident that permanent outages do not occur evenly throughout the year but are concentrated in certain months, namely February, March, April, and November. This indicates a pattern of sporadic yet clustered disturbances, which are generally influenced by environmental conditions or external activities during specific periods.

Regarding internal disturbances, a total of 9 incidents were recorded, with the largest contribution coming from category I-3 (transformers and related equipment) with 5 incidents, followed by I-1 (JTM components) with 4 incidents. Meanwhile, categories I-2 and I-4 showed no outages. This indicates that internal issues predominantly occur in primary distribution equipment, particularly transformers, which are prone to performance degradation due to aging, overloading, or suboptimal maintenance.

On the other hand, external disruptions accounted for a higher number, totaling 13 incidents. The most prevalent disruptions originated from category E-3 (work by third parties or animals) with 9 incidents, followed by E-1 (trees) with 3 incidents, and E-2 (natural disasters) with 2 incidents, while category E-4 was not recorded. The dominance of these external disturbances indicates that the distribution system is highly vulnerable to factors beyond technical control, particularly human activities and the environment surrounding the network.

When comparing internal and external disruptions, it is evident that external disruptions account for a larger proportion—approximately 59% of total disruptions—while internal disruptions account for about 41%. This confirms that the reliability of the distribution system in the study area is more heavily influenced by external factors than by the technical condition of the equipment itself.

In terms of timing, the peak of disruptions occurred in April, with the highest total number of external disruptions (5 incidents), which is likely related to weather conditions or environmental activities during that period. Meanwhile, the months without disruptions (May through October, as well as December) indicate periods of system stability, which can serve as a reference in evaluating maintenance strategies.

Thus, based on the data analysis, it can be concluded that power distribution network disruptions on the studied feeder lines are dominated by external factors, particularly third-party and environmental activities. Therefore, efforts to improve reliability should not only focus on technical maintenance but also incorporate preventive approaches based on environmental and social factors, such as regulating the areas surrounding the network and raising public awareness regarding electrical safety.

3.2. Data Processing

Data processing is carried out using the FTA (Fault Tree Analysis) method. The FTA method is used to identify basic events or combinations of basic events that cause power distribution network disruptions.

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The following are the steps used in FTA, as explained below:
1. Identify Undesirable Events (errors) in the System.

The stage of identifying faults in the power distribution system begins with understanding the initial conditions of the network. The distribution system starts from the main substation as the power distribution center for a customer area with loads that vary over time. From the main substation, electrical energy is distributed through the medium voltage network, then the voltage is reduced using distribution transformers before entering the low voltage network and finally reaching the customer.

Once the system is understood, the next step is to identify undesired events, which are undesirable conditions in the system that can cause disruption to the distribution of electrical energy. These disruptions can originate from various parts of the electrical power system, ranging from power plants (e.g., fuel shortages or generator malfunctions), transmission systems (step-up transformer or transmission cable malfunctions), to distribution systems (malfunctions in substations, medium-voltage networks, distribution transformers, low-voltage networks, and customer installations).

From these various undesired events, one event is selected as the most important to be used as the Top Level Event at the top of the fault tree. The Top Level Event must meet three criteria, namely it must be clearly defined, observable, and its frequency must be measurable. In this context, medium voltage distribution network disturbances are defined as the Top Level Event. Next, the event is broken down to a lower level until the basic events, which are the most fundamental causes, are obtained, which are then arranged in the form of a fault tree diagram.

2. Creation of a Fault Tree

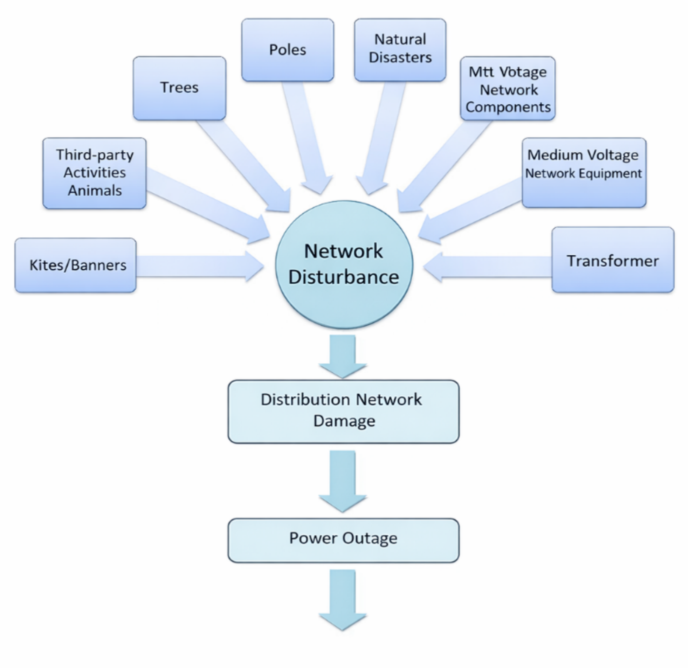

Figure 2. General Causes and Effects of Electrical Distribution Network Disruptions

The electric power distribution system is a critical subsystem within the electric power system that functions to transmit electrical energy from substations to end consumers. The reliability of the distribution system serves as a key indicator of the quality of electric power service, which is measured by supply continuity, outage frequency, and outage duration. In practice, distribution networks are highly vulnerable to outages caused by various external and internal factors, necessitating a comprehensive analysis of the causes and impacts of such outages [1], [6].

a. Network Disturbance

A network disturbance is defined as an abnormal condition that disrupts the normal operation of the power system. These disturbances can be symmetrical or asymmetrical, such as single-phase, two-phase, or three-phase ground faults. Disturbances in distribution networks are generally temporary (temporary faults), but under certain conditions they can develop into permanent faults (permanent faults) that require physical repairs to the system [2], [10].

In addition, the occurrence of faults is closely linked to the performance of protection systems. Protection systems such as circuit breakers and reclosers are designed to quickly isolate faults in order to prevent more extensive damage. However, this isolation process directly results in an interruption of the power supply to consumers [4].

b. Causes of Disorders

Trees is one of the main causes of outages in the power distribution network. Uncontrolled tree growth around the network can lead to direct contact with conductors, especially during high winds. This contact can cause short circuits or flashovers that trigger outages [9]. Therefore, vegetation management is a key strategy for improving the reliability of the distribution system.

Poles serve as support structures for the distribution network. Damage to poles caused by aging, corrosion, excessive mechanical loads, or environmental conditions can lead to structural instability. Pole failure can result in the collapse of the network and widespread power outages [6].

Natural disasters such as lightning, high winds, floods, and earthquakes have a significant impact on distribution systems. Lightning, for example, can cause overvoltage that damages electrical equipment, while high winds can knock down trees or damage power lines [2]. The increasing intensity of natural disasters due to climate change also poses a challenge to maintaining the reliability of the electric power system.

Medium-voltage network components such as insulators, conductors, fuses, and switchgear play a vital role in maintaining system continuity. Material degradation due to aging, contamination, and overvoltage can lead to component failure. These failures are often the source of internal disturbances in distribution systems [6], [10].

Transformers are a key component in stepping down voltage before it is supplied to consumers. Faults in transformers can be caused by overloads, insulation failures, or thermal faults. These conditions can trigger the protection system to trip, resulting in widespread power outages [1].

Foreign objects such as **kites or banners** that become entangled in power lines can cause short circuits or insulation failures. This phenomenon frequently occurs in urban areas and densely populated neighborhoods and is one of the significant external factors [8].

Construction activities by third parties, such as excavation or the use of heavy machinery near power lines, can cause damage to the distribution infrastructure. In addition, animals such as birds, rats, and monkeys can also cause disruptions by coming into contact with or damaging electrical components [13].

c. Distribution Network Damage

Recurring outages or those not addressed promptly can cause permanent damage to the distribution network. This damage includes conductor breaks, damaged insulators, transformer failures, and damage to protection systems. According to power system reliability evaluations, these failures contribute to an increase in reliability indices such as SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index) [4].

Network damage also impacts operational efficiency and maintenance costs. Therefore, a condition-based maintenance strategy is needed to detect potential damage early on [7].

d. Power Outage

Power outages are a direct consequence of disruptions and damage to the distribution network. Outages can be temporary or prolonged, depending on the type of disruption and the speed of resolution. The impact of outages is felt not only by residential consumers but also by the industrial, economic, and public service sectors [5].

In the context of modern power systems, improving reliability is a top priority through the implementation of the smart grid concept. This technology enables real-time fault detection as well as faster and more efficient system restoration [7].

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e. Mitigation Strategies and Reliability Improvement

To reduce outages and improve the reliability of the distribution system, several strategies can be implemented, including:

a) Regular vegetation trimming
b) Improving the quality and standards of network materials
c) Implementing adaptive protection systems
d) Utilizing smart grid and IoT technologies
e) Data-driven monitoring for outage prediction

An analysis of the root causes of power distribution network outages in the Bengkalis region indicates that the prevalence of outages caused by "third-party work/animals" cannot be viewed as a purely technical phenomenon, but rather as the result of a complex interaction between environmental, technical, social, and management system factors. Empirically, disruptions caused by animals are recorded as contributing significantly to the total number of network disruptions, indicating a close correlation between geographical conditions and the characteristics of the distribution network in use [24]. As a coastal region with a relatively dense vegetation ecosystem, Bengkalis has a high level of biodiversity, thereby increasing the potential for interaction between wildlife—such as monkeys, snakes, and civets—and the power grid infrastructure. This situation is exacerbated by the lack of adequate physical barriers between the distribution network and the natural environment, allowing animals to easily use conductors or poles as pathways, which can ultimately lead to short circuits or insulation failures [19].

In addition to environmental factors, technical aspects of the distribution network are also a major cause of frequent outages. Most distribution networks in Bengkalis still use overhead line systems, which are inherently open and vulnerable to external disturbances. This openness leaves the network without sufficient protection against direct contact with foreign objects, whether from animals or human activities. Limitations in the installation of additional protective devices such as animal guards, insulated conductors, or more modern insulation systems further increase the risk of outages [19]. From the perspective of power system reliability, network designs that are not adapted to local environmental conditions will increase the frequency of outages and lower reliability indices such as SAIFI and SAIDI.

From a social perspective, community activities also contribute significantly to power grid disruptions. Activities such as construction work carried out without coordination with utility providers, the installation of banners or flags near power lines, and the practice of flying kites in grid areas are major sources of disruption. This reflects the public's still-low level of awareness regarding electrical hazards and a lack of understanding of safe zones around distribution networks. Studies show that human activities can be the primary cause of disruptions in the distribution system if not balanced by adequate regulations and education [25]. Thus, social factors in Bengkalis play a crucial role in increasing the probability of external disruptions.

3. The location of disturbances in the distribution network system can be seen in the table below.

Table 2. The Performa of Identification Of The Location, Cause, And Effects Of Damage To The Electricity Distribution Network System

Location of Damage	Damaged Component	Result of Damage	Cause of Damage
Main Substation	Power Circuit Breaker (PMT)	Component not securely fastened, PMT open	Installation Error
	Disconnect Switch (PMS)	Loose component	Installation error
Medium Voltage Network (JTM)	Electric pole	Electric pole collapsed	Natural disturbance
	Power cable	Power cable broken	Natural disturbance
			Human disturbance
			Installation error
			Material defect
	Insulator	Insulator damaged	Component failure
	Fuse	Fuse leaking	Installation error
	Lightning arrester	Lightning arrester damaged	Natural disturbance
Distribution Transformer	Transformer	Transformer jumper damaged	Component failure
		Transformer damaged	Component failure
Low Voltage Network (JTR)	Relay	Short circuit	Natural disturbance
			Animal disturbance
	Connector	Connector unstable	Human disturbance
			Natural disturbance

The location of damage to the distribution network for all components in the electrical distribution network system can be identified as PMT and PMS switches, insulators, connectors, fuses, lightning arresters, APPs, MCBs, and others. The results of this characterization will then be used to create a fault tree. Fault Analysis in Electrical Distribution Network Systems (Undesirable Events).

This analysis aims to identify various events that can disrupt the distribution of electrical energy to customers. These disruptions can originate from various factors, such as fuel shortages at power plants, construction or work activities by PLN or other agencies, installation of new electrical equipment, maintenance activities, and damage to the electrical distribution network itself. The main focus of the problem being studied is damage to the electrical distribution network system.

The electricity distribution system consists of five main parts, namely substations, medium voltage networks, distribution transformers, low voltage networks, and customer networks. Most disturbances are caused by damage to equipment used in the electricity distribution process. Such damage can be triggered by natural factors, humans, animals, material quality, or installation errors.

Based on the location of the damage, disruptions at the substation can occur in the power breakers and disconnect switches. In the medium voltage network, damage can include cable, insulator, fuse, and lightning arrester disruptions. In distribution transformers, disruptions can occur in the internal components of the transformer or jumpers. Meanwhile, in low-voltage networks and customer networks, damage generally occurs in relays, connectors, insulators, jumpers, limiting and measuring devices, and MCBs (Mini Circuit Breakers).

4. Drawing a Fault Tree Based on Distribution Network System Identification

The fault tree diagram is created after identifying all faults that occur in the electrical distribution network system. The fault tree is created using Boolean symbols. Standardization of these symbols is necessary for communication and consistency of the fault tree. The logic used in the fault tree diagram is “OR” logic, which illustrates that one input condition can cause an output condition to occur. Therefore, the output can occur if one, several, or all of the input conditions occur. The following is a fault tree diagram, which can be seen in the image below.

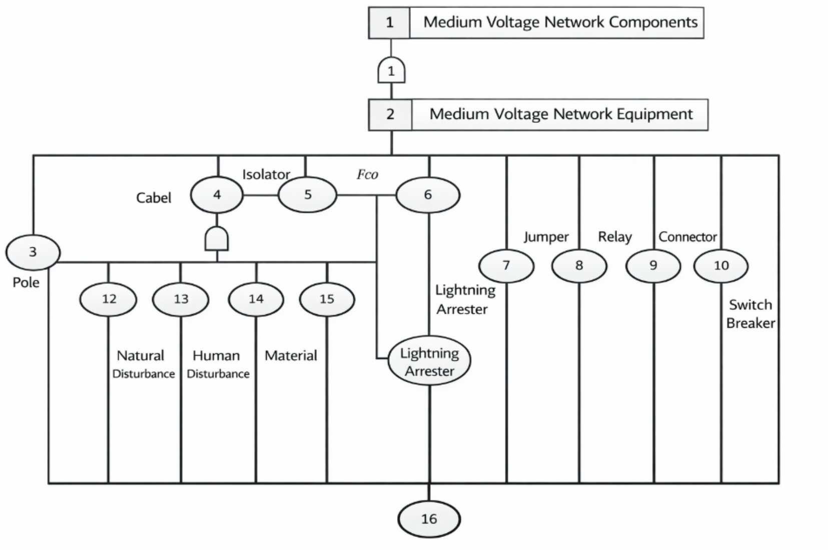

Figure 3. Fault Tree

The numbers in the error tree diagram can be seen in the table below.

Table 3. The Performa of Meaning Of Numbers In The Tree Of Error Image

No	Description
1	Damage to medium voltage network components (JTM)
2	Damage to medium voltage network equipment (JTM)
3	Damage to poles
4	Damage to cables
5	Damage to insulators
6	Damage to fuses (fuse cut outs)
7	Damage to lightning arresters
8	Damage to jumpers
9	Damage to relays
10	Damage to connectors
11	Damage to circuit breakers (PMS)
12	Natural disturbances
13	Human disturbances

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No	Description
14	Material disturbances
15	Installation disturbances
16	Electrical disturbances

Fault tree analysis is used to determine the minimum cut set, which is a combination of basic events that directly cause damage to the electrical distribution network. Based on the analysis results, six main basic events were identified, namely natural disturbances, human disturbances, animal disturbances, electrical component disturbances, material disturbances, and installation errors. Natural disturbances include strong winds, lightning, floods, and heavy rain, which can cause damage to cables, power poles, lightning rods, and connectors. Human disturbances are also a significant factor, such as kite flying or digging PDAM channels, which can damage the distribution network.

In addition, animals such as birds, geckos, and snakes that are active around electrical cables can cause short circuits or power outages. Electrical component failures generally occur due to poor equipment quality, while material failures are caused by old materials that are prone to corrosion, wear, or breakage. Installation errors can also cause damage if the network is not installed according to procedure or components are not installed properly. After the fault tree diagram has been compiled, the next step is to determine the minimum cut set to identify the basic events that contribute most to damage to the electrical distribution network.

5. Determination of the Minimum Cut Set

Minimal Cut Set is a collection of basic events or combinations thereof. If events occur simultaneously, then a Top Level Event will definitely occur. The determination of the minimal Cut Set is based on the fault tree diagram. The following is a description of all events that occur based on the fault tree, namely:

Top level event

T = 1

T = 2

T = 3 + 4 + (12 + 13 + 14 + 15) + 5 + 6 + 7 + 8 + 9 + 10 + 11

After all incidents have been described, the minimum cut set is obtained as follows: 3 + 4 + 5 + 6 + 7 + 8 + 9 + 10 + 11

Description:

1. Pole damage (code 3)
2. Cable damage (code 4)
3. Insulator damage (code 5)
4. Fuse malfunction (code 6)
5. Lightning rod malfunction (code 7)
6. Jumper damage (code 8)
7. Relay damage (code 9)
8. Connector damage (code 10)
9. Circuit breaker damage (code 11)

Output from the minimum cut set consisting of several Basic Events causing damage to the electrical distribution network.

6. Proposed Improvements to the Electricity Distribution Network

Improvement proposals were made after analyzing the FTA, based on the most significant factor causing power outages, namely damage to the distribution network. Damage to the distribution network not only causes power outages, but also affects the quality of PLN's service to electricity customers. To improve service quality and reduce outages, the following improvement proposals were made based on the existing electrical distribution network system:

a) Main Substation

Problems at substations are generally caused by poor installation of components, such as power breakers (PMT) and disconnect switches (PMS) that are not securely fastened, which can interfere with electricity distribution and have a widespread impact on customers. To prevent damage, regular inspections of all components are required, including checking the contact resistance on cables and switches, as high contact resistance can cause excessive heat that can be detected using a thermovision device. If high temperatures are found at the connections, the steps to take include shutting down the network, measuring and cleaning the contacts, replacing damaged clamps, and reconnecting, ensuring that the contact resistance is in good condition before the network is reactivated.

b) Medium Voltage Network

Problems with medium voltage networks are generally caused by damage to equipment in overhead lines, such as electricity poles, cables, insulators, fuses, and lightning arresters, most of which are triggered by natural disturbances. In addition, disturbances can also occur due to poor contact resistance at connections, causing excessive heating. One solution offered is to replace overhead lines with underground cables, even though the cost is higher, because underground cables have a lower risk of disturbance and can improve the quality of electricity distribution services. Low Voltage Network

Problems in the low voltage network are mostly due to natural disturbances such as broken low voltage jumpers, broken insulators, or leaking fuses. In addition to natural disturbances, component and installation disturbances also often occur. The proposed solution for improvement is to actively clean the network of tree branches that can interfere with the flow of electricity.

c) Customer Network

A common problem in customer networks is short circuits caused by electrical faults, which can lead to fires. These short circuits are caused by damage to MCBs. In addition to damage to MCBs, damage to connectors and limiting and measuring devices often occurs in customer networks. Energy waste is also a common problem in customer networks. The proposed solution for improvement is the installation of energy-saving devices. A capacitor bank is a device that can be used to improve the power factor, which affects the magnitude of the current. The installation of capacitor banks will provide the following benefits: increased network capacity to distribute power, optimized costs due to reduced cable size, reduced “drop voltage” values, reduced current or temperature rise in cables, thereby reducing power loss. The use of capacitor banks is beneficial to both parties: from the customer's perspective, bills can be reduced, and from PLN's perspective.

d) Proposed Improvements to Distribution Network Damage

Proposed improvements to distribution network damage include scheduled inspections of distribution network equipment to anticipate damage, replacement of electrical distribution lines from overhead lines to underground lines, maintenance programs, transformer power management or data collection programs, distribution planning programs, adding Thermovision equipment to observe and detect distribution network damage more quickly and accurately, installing networks in accordance with established procedures, and installing capacitor banks, which are devices to improve the power factor, thereby affecting the amount of current flowing and reducing power loss.

4. CONCLUSION

Root Cause Analysis

Based on data on distribution network outages in the Bandung Feeder in 2025, it is evident that outages were primarily caused by external factors, particularly category E-3 (third-party work/animals), as well as some internal factors such as JTM components and transformers.

Upon further investigation using the Fault Tree Analysis (FTA) approach, the root causes extend beyond technical incidents to more fundamental non-technical factors, namely:

1) Environmental factors:

The Bengkalis region has geographical characteristics marked by dense vegetation and tropical weather conditions (wind, rain, lightning) that can potentially cause disruptions such as fallen trees and flashover.

2) Community social factors:

Community activities such as flying kites, hanging banners, and third-party work near the power lines are the primary causes of disruptions. This indicates a low level of awareness regarding electrical grid safety.

3) Infrastructure and maintenance factors:

Several internal disruptions, such as damage to JTM components and transformers, indicate a decline in equipment quality or suboptimal maintenance activities.

Resolution Time & Incident Category

The data used in this study consists of data on power distribution network outages during the period from January to December 2025, with monthly time resolution.

Outage categories are classified into two main groups:

a) Internal Faults

I-1: JTM Components
I-2: JTM Equipment
I-3: Transformers and Related Equipment
I-4: Power Poles

b) External Faults

E-1: Trees
E-2: Natural disasters

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E-3: Third-party work / animals
E-4: Kites / other human activities

However, the data has the following limitations:

a) No detailed time resolution (daily/hourly)
b) No outage duration
c) No specific outage location (spatial data)

The Fault Tree Analysis (FTA) method used in this study has proven capable of systematically identifying the cause-and-effect relationships of faults through a top-down approach until the root cause (basic event) is identified. However, FTA is a conventional method that has limitations in representing dynamic system conditions, primarily because it does not account for real-time event probabilities or changes in network operational conditions. Furthermore, this method has not been integrated with power system reliability parameters, so the resulting analysis remains descriptive and limited to identifying the causes of disturbances. Thus, the use of FTA in this study emphasizes applied case studies rather than the development of new analytical methods.

To enhance the scientific contribution of research, it is necessary to develop more comprehensive analytical methods. One approach that can be taken is to integrate power system reliability indices, such as SAIDI and SAIFI, so that the analysis focuses not only on the frequency of outages but also considers their impact on customers. Additionally, the implementation of predictive maintenance concepts can be used to anticipate potential failures based on historical outage data, thereby enabling maintenance activities to be carried out more effectively and efficiently. Another development is the implementation of risk-based maintenance, where the priority of addressing outages is determined based on the level of risk posed, both in terms of frequency and impact. With this approach, the research is not only analytical but also provides strategic contributions to the management of power distribution system reliability.

Based on the results of the analysis conducted, it can be concluded that power distribution network outages in the Bandung Feeder are primarily caused by external factors influenced by environmental conditions and community activities. The Fault Tree Analysis (FTA) method used was able to systematically identify the root causes of outages; however, it still has limitations in measuring reliability levels and predicting potential future outages. Therefore, further research through the integration of reliability indices, the implementation of predictive maintenance, and a risk-based approach is essential to improve the quality of analysis and make a more significant contribution to enhancing the reliability of the electrical power distribution system.

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CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

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