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Analysis of Cause of Power Distribution Network Failures Using the Fault Tree Analysis Method at PT PLN Persero ULP Kuranji

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Abstract— Electricity is a fundamental necessity in modern life, making the reliability of power distribution systems critical for consistent energy delivery to consumers. PT PLN (Persero) ULP Kuranji is responsible for power distribution in its service area, but frequent disturbances still compromise service quality. This study aims to identify and analyze the root causes of these distribution network failures using the *Fault Tree Analysis* (FTA) method, specially at ULP Kuranji using 2024 data. Data were gathered through literature review, field observations, and interviews with the Technical Team Leader of ULP Kuranji. The research methodology involved failure identification, fault tree construction, minimum cut set determination, and FTA-based analysis to formulate corrective recommendations. The results show that disturbances are mainly caused by external factors such (vegetation, weather conditions, animals, and third-party interference), an internal issue (component and equipment failures within the Medium Voltage Network (MVN). The analysis identified five basic events as primary root causes: natural disturbances, animal or third-party interference, component failures, material or equipment faults, and installation errors. Recommended mitigation measures include routine maintenance, protective risk inspection, adopting monitoring technologies, and infrastructure/equipment upgrades.

Keywords: Distribution Network, Distribution Network Disruption, and Fault Tree Analysis (FTA).

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1. Introduction

Electricity is a vital necessity in daily life that supports various household, industrial, and public service activities. Therefore, a reliable electrical distribution system is required to ensure stable power delivery to the end users. The reliability of a distribution system refers to its ability to deliver electricity effectively and consistently to customers [1]. The main objective of the distribution system is to deliver electrical energy generated from large-scale power plants (*bulk power houses*) to consumers [2]. In general, the supply of electrical power consists of three main stages, namely the generation system, the transmission system, and the distribution system [3]. The distribution network consists of various components, including power cables, distribution transformers, switchgear, electrical protection devices, and other equipment used to regulate the flow of electricity and ensure a stable and safe power supply [4]. Electrical energy is delivered to consumers through a distribution network that consists of a 20 kV Medium Voltage Network and a 220/380V Low Voltage Network [5].

As the leading entity in the provision of national electricity, PT PLN (Persero) continuously strives to enhance the quality and reliability of the electrical system in order to meet the needs of the public [6]. PLN (Persero) ULP Kuranji, as a state-owned electricity company responsible for the distribution of electrical energy, is accountable for ensuring optimal power delivery to all customers within its service area. The process of electrical energy distribution is inseparable from disturbances in the distribution system, which are defined as any events that cause abnormal conditions in the delivery of electrical power [7] . he indications of disturbances may originate from within the system (internal) or from outside the system (external) [8]. According to the 2024 disturbance records, external interruptions in the power distribution network at PT PLN (Persero) ULP Kuranji were primarily

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attributed to trees falling onto the Medium Voltage Network (MVN), natural factors such as extreme weather conditions including heavy rainfall and storms, animal interference caused by civets and squirrels, and third-party incidents involving broken Wi-Fi cables coming into contact with the MVN. In contrast, internal disturbances were mainly caused by equipment malfunctions or component failures within the MVN, such as damaged or broken pin insulators. These disturbances have led to a decline in the quality of electricity delivery and the level of service provided to customers.

This study was conducted to identify and analyze disturbances in the electrical distribution network at PT PLN (Persero) ULP Kuranji, with the aim of establishing appropriate mitigation strategies to minimize the occurrence of such disturbances in the future. A suitable method for conducting such an analysis is the Fault Tree Analysis (FTA). FTA is a method used to analyze the causes of system failures[9]. It employs a top-down approach, in which the analysis begins from the system failure or disturbance (top event) down to the root causes. The results of this failure analysis are presented in a fault tree using Boolean logic symbols. Based on this analysis, appropriate corrective actions can be identified to reduce the causes of disturbances or failures in the power distribution network.

2. Method

This research is focused on the analysis of distribution network disturbances at PT PLN (Persero) ULP Kuranji using the Fault Tree Analysis (FTA) approach. The research flow diagram is illustrated in Figure 1.

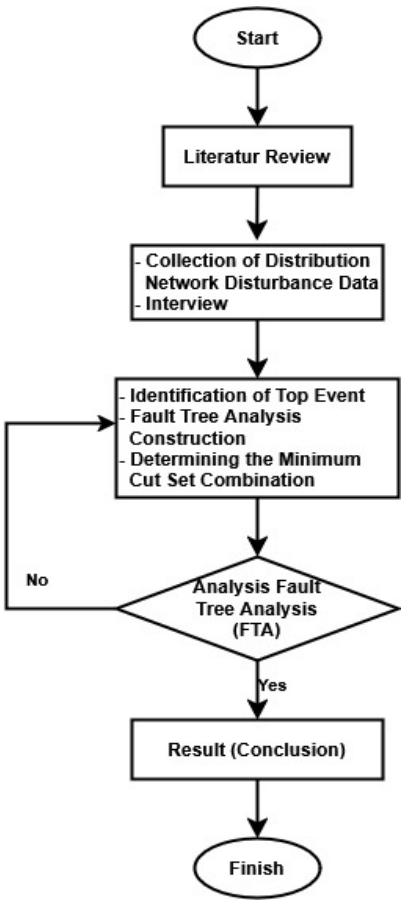


Figure 1. Research Flowchart

In essence, the research method is a scientific approach used to obtain data for specific purposes and applications [10]. Without a proper understanding of data collection techniques, researchers will not be able to obtain data that meet the established standards [11]. In this research, the method used is a qualitative approach, which is based on positivist philosophy and is employed to study objects in a natural setting.

As shown in Figure 1, this research began with the identification of its primary objective, which was to analyze disturbances occurring in the electrical distribution network at PT PLN (Persero) ULP Kuranji. The next stage involved conducting a literature review of previous studies and other relevant sources that support the topic of this research. Subsequently, the study proceeded with the collection of distribution network disturbance data from PT PLN (Persero) ULP Kuranji for the period of January - December 2024, along with direct field observations through interviews with the Technical Team Leader of ULP Kuranji.

In this study, data processing was carried out using the Fault Tree Analysis (FTA) method. Fault Tree Analysis (FTA) method is one of the most prominent techniques and has been widely applied across various industrial sectors [12]. This method enables the identification of the causes of disturbances or failures in the distribution network by starting with the identification of the top event and then detailing the underlying causes leading to the top event, down to the root cause. The analysis is then illustrated in a fault tree diagram using logic gate.

3. Result and Analysis

3.1 Data Collection

The following is the disturbance data recorded at PT PLN (Persero) ULP Kuranji in the year 2024. Disruption Cause Data January – December 2024:

Table 1. Disruption Cause Data January-December 2024

Month	Disturbance										Total
	External					Internal					
	E1	E2	E3	E4	Quantity	I1	I2	I3	I4	Quantity	
January	-	1	1	-	2	-	-	-	-	0	**2**
February	-	1	-	-	1	1	-	-	-	1	**2**
March	-	-	4	-	4	-	-	-	-	0	**4**
April	-	-	1	-	1	-	1	-	-	1	**2**
May	-	-	1	-	1	-	-	-	-	0	**1**
June	-	-	-	-	0	-	-	-	-	0	**0**
July	-	-	-	-	0	-	-	-	-	0	**0**
August	1	-	2	-	3	1	-	-	-	1	**4**
September	-	-	1	-	1	1	-	-	-	1	**2**
October	-	-	-	-	0	-	-	-	-	0	**0**
November	-	-	1	-	1	-	-	-	-	0	**1**
December	1	-	-	-	1	-	-	-	-	0	**1**
Total	2	2	11	0	15	3	1	0	0	4	**19**

From Table 1, it can be observed that the disturbances occurring in the electric power distribution network at PT PLN (Persero) ULP Kuranji throughout 2024 originated from both external and internal factors. Based on the data presented in the table, there were a total of 15 external disturbances and 4 internal disturbances recorded. Furthermore, it can be seen that the highest frequency of disturbances at PT PLN (Persero) ULP Kuranji occurred in March and August 2024.

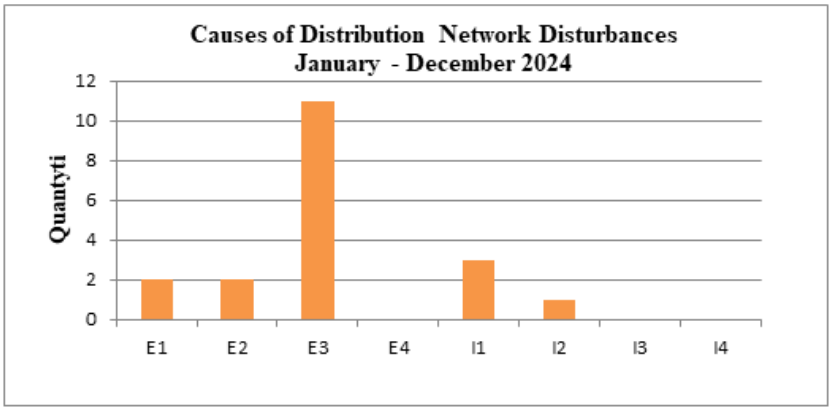


Figure 2. Graph of Causes of Distribution Network Disturbances

Description :

E1 : Tree
E2 : Natural causes
E3 : Animals / Third party
E4 : Kites /streamers, etc
I1 : Medium Voltage Network Components
I2 : Medium Voltage Network Equipment
I3 : Transformer
I4 : Pole

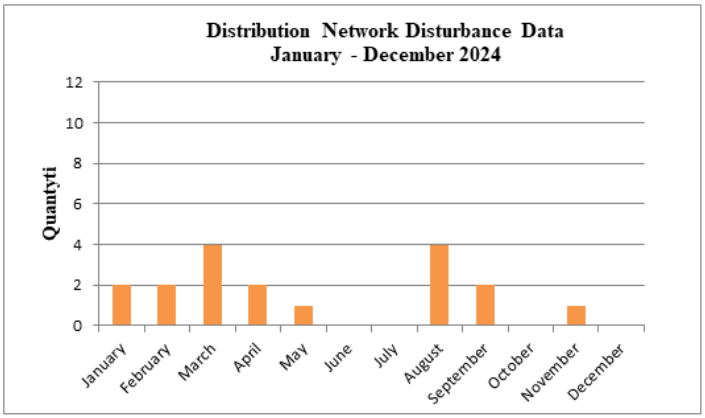


Figure 3. Graph of Distribution Network Disturbances

Based on Figure 2, the graph illustrates a comparison of disturbances in the electric power distribution network from January to December 2024. External disturbances were caused by tree-related incidents (E1) with a total of 2 occurrences, natural factors (E2) with 2 occurrences, and animal or third-party interference with 11 occurrences. Meanwhile, internal disturbances were caused by faults or damage to Medium Voltage Network (MVN) components (I1) with 3 occurrences and faults or damage to MVN equipment (I2) with 1 occurrence. Furthermore, Figure 3 presents a comparative graph of distribution network disturbances for each month in 2024.

Based on field observations and interviews with Mr. Agung Saferlin, the Technical Team Leader at PT PLN (Persero) ULP Kuranji, it was revealed that the most frequent disturbances in 2024 were caused by external factors. According to the source, the primary cause of disturbances was interference from animals or third parties, particularly from animals such as civets and squirrels crossing the network. In addition, other external disturbances were caused by natural factors during extreme weather conditions, such as heavy rain and storms, as well as by trees specifically, branches falling on the medium voltage network (MVN). Meanwhile, internal disturbances in 2024, based on the same data, were mainly due to failures or damage to MVN components and equipment. These include broken pin insulators, damaged outdoor terminals, and faults in LBS (Load Break Switches) and recloser.

3.2 Data Processing

The Fault Tree Analysis (FTA) approach was used to process the data for this study. The steps involved in Fault Tree Analysis (FTA) are as follows:

1. Identification of Failure /Critical Events (Top Level Event)
   From this disturbance data, Undesired Event (error) can be determined, which is an undesirable event in the distribution network. In the research conducted in the form of disturbances/damage or errors in the distribution network that cause a decrease in the quality of distribution and delivery of electrical energy to customers. So that in the research, an undesired event was obtained which was then used as a top event (peak event), namely **the Electric Power Distribution Network Disturbance.**

2. Contruction of Fault Tree
   Based on the previous identification, the critical event (top event) in this study is identified as Disturbance in the Electrical Power Distribution Network. The fault tree's contruction starts with identifying the location of the disturbance within the power distribution network, involving all components related to electricity distribution. In general, figure. 4 below illustrates the reasons behind in the electrical power distribution network:

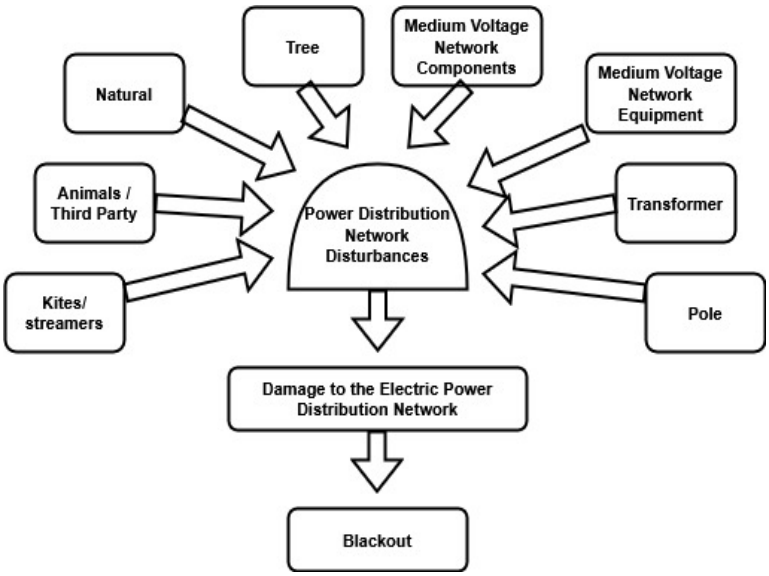


Figure 4. Common Causes of Electrical Power Distribution Network Disturbances

In addition, the determination of the top event will identify combination of events down to lower levels, ultimately reaching the root causes. Therefore, it is necessary to identify the characteristics of disturbance causes based on their location within the distribution network. This relationship can be seen in Table 2 below :

Table 2. Identification of Location, Causes, and Effect Damage to Electrical Distribution Network

Location of Damage	Damage Components	Risk of Failure	Case of Failure
Substation	Circuit Breaker (PMT)	Component Not Securely Attached CB Open	Installation Eror
	Isolator Switch (PMS)	Loose Component	Installation Eror
Medium Voltage Network (JTM)	Electric pole	Electric Pole Collapse	Natural Disturbance
	Electric Cable	Cable break	Natural Disturbance Human Disturbance Installation Disturbance Material Disturbance
	Isolator	Isolator Damage	Components Disturbance
	Fuse	Blown Fuse	Installation Error
Distribution Transformer	Lightning Rod	Damaged Lightning Rod	Natural Disturbance
	Transformator	Transformer Jumper Damage	Components Disturbance
Low Voltage Network	Relay	Short Circuit	Natural Disturbance Animal Disturbance Human Disturbance
	Connector	Unstable Connector	Natural Disturbance

After determining the top-level event and the characteristic of the disturbance causes based on their location within the distribution network, the next step is the the contruction of the fault tree using logic gates. In this study, an ‘OR’ gate is used, as illustrated in Figure. 5 below:

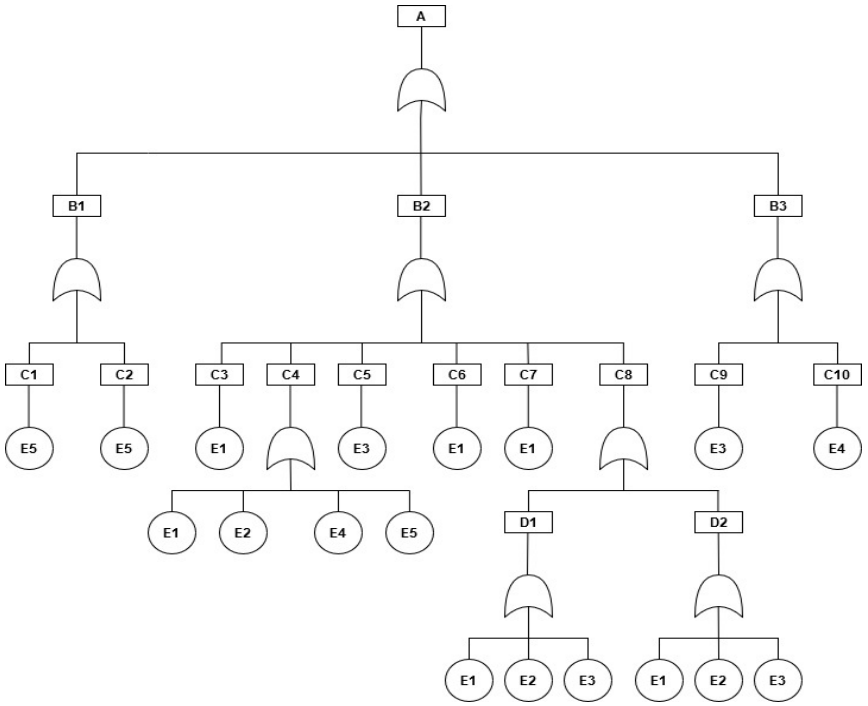


Figure 5. Fault Tree

From the figure above, the notations used in the fault tree can be explaied in Table 3 below:

Table 3. Fault Tree Notation Descriptions

No	Notation	Description
1	A	Disturbance in the electrical power distribution network
2	B1	Fault at the Substation
3	B2	Fault in the Medium Voltage Network
4	B3	Fault in the Distribution Transformer
5	C1	Circuit Breaker (CB) Fault
6	C2	Isolator Switch (DS) Fault
7	C3	Pole Damage
8	C4	Cable Fault
9	C5	Insulator Damage
10	C6	*Fuse Cut Out* Damage
11	C7	Lightning Arrester Damage
12	C8	Protection Relay Fault
13	C9	Transformer Jumper Fault
14	C10	Transformer Damage
15	D1	Load Break Switch (LBS) Disturbance
16	D2	*Recloser* Disturbance
17	E1	Natural Disturbance
18	E2	Animal / Third-party Disturbance
19	E3	Component Disturbance
20	E4	Material/ Equipment Failure
21	E5	Installation Error

3. Determining the Minimum Cut Set

The smallest collection of basic event occurrences that might cause a system failure is know as a Minimum Cut Set. To ascertain the minimal cut set, the analysis starts from the lowest level, identifying the basic events that serve as the root causes of disturbances in the electrical power distribution network. Based on Figure. 5, the fault tree above can be used to determine the cut sets using Boolean algebra, as shown in the table below:

Table 4. Cut Set of Aljabar Booelan

A	= B1 + B2 + B3	C5	= E3
B1	= C1 + C2	C6	= E1
B2	= C3 + C4 + C5 +C6 + C7 +C8	C7	= E1
B3	= C9 + C10	C8	= D1 + D2
C1	= E5	D1	= E1 + E2 + E3
C2	= E5	D2	= E1 + E2 + E3
C3	= E1	C9	= E3
C4	= E1 + E2 + E4 + E5	C10	= E4

The final result of these event combination will indicate the main events that cause the occurrence of the top event. The resulting event combinations are as follows :

T = A

T = B1 + B2 + B3

= (C1 + C2) + (C3 + C4 + C5 + C6 + C7 + C8) + (C9 + C10)

= (E5 + E5) + ((E1) + (E1 + E2 + E4 + E5) + (E3) + (E1) + (E1) + (D1 + D2)) + (E3 + E4)

= (E5 + E5) + ((E1) + (E1 + E2 + E4 + E5) + (E3) + (E1) + (E1) + ((E1+ E2 + E3) + (E1 + E2 + E3)) + (E3 + E4)

After all elements have been outlined, the Boolean combination results in five minimum cut sets as follows: E1 + E2 + E3 + E4 + E5, with the following descriptions:

Descriptions:

Notation E1: Natural Disturbance
Notation E2: Animal / Third-Party Disturbance
Notation E3: Component Failure
Notation E4: Material / Equipment Failure
Notation E5: Installation Error

3.3 Analysis Fault Tree

The Fault Tree Analysis (FTA) was carried out to identify the root causes of disturbances in the electrical power distribution network. Through the fault tree analysis, minimum cut sets consisting of basic events, the fundamental causes of network disturbances can be determined. Therefore, it is essential to enhance the system reability and resilience to reduce or minimize potential disturbances, ensuring the efficient and uninterrupted distribution of electrical power. The following are several recommendations to improve the performance and reliability of the electrical distribution network:

1. **Relay and Protection System Improvements**
   Aimed at ensuring the protection system operates accurately and can respond effectively any potential disturbances. The purpose of the protection system in the distribution network is to minimize disturbances caused by interruptions in the distribution of electrical power and to provide optimal protection for operators, areas, and equipment in the event of a permanent fault [14].

2. **Cable and Insulator Repairs**
   When damaged cables or insulator are identified, they should be replaced to improve the performance and reliability of the power distribution network.

3. **Natural Disturbance Mitigation**
   Routine inspections of the network are essential to prevent disruptions caused by severe weather conditions. In addition, regular tree trimming around the network should be carried out to minimize the risk of falling trees damaging the distribution lines.

4. **Technology Utilization**
   With the advancement of modern technology, monitoring system can be used to detect faults in the power distribution network. This enables maintenance work to be carried out more efficiently and effectively.

5. **Infrastructure and Equipment Improvements**
   Regular inspections and maintenance of infrastructure and equipment within the distribution network are necessary to enhance the quality and reliability of electricity distribution services.

4. Conclusion

Based on the results of the study conducted at PT PLN (Persero) ULP Kuranji, it can be concluded that disturbances in the electric power distribution network are influenced by a combination of external and internal factors. External factors include tree interference with the network, adverse weather conditions, disturbances caused by animals such as civets and squirrels, as well as third-party activities in the form of WiFi cables coming into contact with the network. Meanwhile, internal factors are related to damage to components and equipment of the Medium Voltage Network. The application of the Fault Tree Analysis (FTA) method identified five basic events as the main causes of distribution network disturbances, namely natural disturbances, animal or third-party disturbances, component failures, material or equipment failures, and installation-related disturbances. Based on these findings, improvements in network reliability can be achieved through regular inspection and review of the network, implementation of inspections to identify potential disturbances, utilization of supporting technologies, and enhancement of infrastructure and equipment maintenance.

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