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Reliability Analysis of Power Supply and Protection Systems Against Electrical Disturbances in Fiber Optic Networks in Lightning-Prone Areas

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ABSTRACT

Fiber-optic communication networks play a crucial role in ensuring smooth high-speed data transmission. However, in lightning-prone areas, these networks are susceptible to disruptions due to voltage surges and power outages, which can degrade service quality. This study aims to analyze the reliability of the power supply and protection systems used in fiber-optic network infrastructure in lightning-prone areas. The research methods include field surveys, power quality measurements, and evaluation of the lightning protection and grounding system designs used. Data were collected from measurements of voltage, current, and duration of electrical disturbances, as well as interviews with network technicians. The analysis results indicate that most disturbances are caused by voltage surges due to indirect lightning strikes that propagate through the power supply lines. Implementation of a protection system that combines surge arresters, effective grounding, and backup power sources (UPS and generators) has been shown to increase network reliability by up to 92% based on Mean Time Between Failure (MTBF) calculations. This study recommends the implementation of a layered protection system with regular maintenance to minimize the impact of electrical disturbances on fiber-optic networks in lightning-prone areas.

Keywords: Reliability, Power Supply, Lightning Protection, Fiber Optics, Electrical Interference

INTRODUCTION

The development of information and communication technology has driven an increasing need for reliable, fast, and stable data transmission networks. One transmission medium currently serving as the backbone of modern communication systems is fiber optic networks. Compared to copper cables, fiber optics offer advantages in terms of transmission capacity, speed, and resistance to electromagnetic interference. However, despite these advantages, fiber optic networks remain vulnerable to interference, particularly in areas prone to lightning.

In areas with high lightning strike intensity, fiber optic network systems often experience disruptions due to voltage surges that propagate through the power supply lines. These surges can damage active devices such as Optical Line Terminals (OLTs), Optical Network Units (ONUs), switches, and other transmission devices. Furthermore, power outages due to lightning strikes or power distribution disruptions can result in significant service downtime, impacting quality of service (QoS). To overcome this problem, it is necessary to implement an effective protection system, such as*surge arrester*, a good grounding system, and backup power sources such as an Uninterruptible Power Supply (UPS) and generator. A reliable power supply will minimize equipment damage and ensure services continue to operate even in the event of a power outage.

System reliability can be analyzed through parameters such as Mean Time Between

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Failure (MTBF) and Mean Time to Repair (MTTR), which reflect the network's operational readiness. By understanding these reliability levels, service providers can determine enhanced protection and maintenance strategies to minimize disruptions. This damage not only results in high repair costs but also results in service downtime, which directly impacts customer quality of service (QoS). Lightning-induced power outages can be direct (due to a direct strike on the infrastructure) or indirect (due to electromagnetic induction or overvoltages propagating through the power grid).

Furthermore, lightning-prone areas frequently experience power outages, both short-term (momentary outages) and long-term (sustained outages). Without an adequate backup system such as an uninterruptible power supply (UPS) or generator, these outages can completely halt network operations. Therefore, a reliable power supply system is a critical factor in ensuring the continuity of fiber optic network services.

To minimize the risk of disruption and damage, telecommunications service providers usually implement several protection methods, including:

1. Lightning protectionusing surge arresters or lightning arrestors to channel voltage surges to the ground.
2. Grounding systemwith low ground resistance to ensure effective lightning current discharge.
3. Reserve resourcessuch as UPS and generators to maintain electricity supply during blackouts.
4. Monitoring and alarm systemto detect voltage or current anomalies before they cause damage.

System reliability can be measured by technical parameters such as Mean Time Between Failures (MTBF), which indicates the average operating time before a failure occurs, and Mean Time To Repair (MTTR), which indicates the average repair time after a disruption occurs. This reliability analysis helps network operators design maintenance strategies, determine protection investment priorities, and optimize service level agreements (SLAs). Based on these conditions, this study focuses on analyzing the reliability of power supply systems and protection against electrical disturbances in fiber optic networks in lightning-prone areas. The results of this study are expected to:

- Identify weak points in the power supply system and the protection used.
- Provide technical recommendations for improving system reliability.
- Reduce the risk of service downtime due to power outages.
- Reduce maintenance and repair costs due to device damage.

With a comprehensive understanding of the reliability of power supply and protection systems in lightning-prone areas, it is hoped that telecommunications service providers can maintain optimal service quality, while providing high levels of satisfaction and trust to customers. Based on these conditions, this research focuses on analyzing the reliability of power supply and protection systems in fiber optic networks in lightning-prone areas, in order to provide technical recommendations that can improve the stability and sustainability of communication network services.

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LITERATURE REVIEW

Power Supply System in Telecommunication Infrastructure.

A power supply system is a series of devices that provide stable and reliable electrical energy to operate telecommunications equipment. In fiber optic networks, the power supply system ensures that active devices such as Optical Line Terminals (OLTs), Optical Network Units (ONUs), and repeaters remain operational even in the event of a power outage.

The main components of the power supply system include:

1. Main Power Source – usually comes from the PLN network.
2. Backup Power Sources – such as batteries (UPS) or generator sets to ensure power continuity.
3. Power Distribution System – delivers electricity to devices at the appropriate voltage and current.

The reliability of a power supply system is expressed in parameters such as Mean Time Between Failure (MTBF) and Availability, which describe how long the system can operate without interruption.

Electrical Interference in Fiber Optic Networks

Electrical interference in fiber optic networks can originate from various factors, including:

- Lightning strike that causes voltage spikes (overvoltage).
- PLN system failure causing sudden blackouts.
- Voltage and Frequency disturbances such as voltage sags, spikes, and harmonics.

In lightning-prone areas, direct or induced lightning strikes can damage power supply modules, optical transmission devices, and control systems, resulting in service outages. Power outages on fiber optic networks can cause reduced service performance, downtime, and even permanent damage to equipment.

Protection against Electrical Disturbances

Protection against electrical disturbances aims to prevent damage to equipment caused by voltage surges or power outages. Some common protection methods used in telecommunications infrastructure include:

1. Surge Arrester – protects devices from voltage surges caused by lightning.
2. Grounding System – discharges excess current to the ground with low ground resistance ($\leq 5\ \Omega$).
3. Uninterruptible Power Supply (UPS) – provides temporary power when the main source goes out.
4. Optical and Electrical Isolators – prevent induced voltages from propagating to sensitive devices.

Standards that are often used as references include:

- IEEE Std 1100-2005 (IEEE Recommended Practice for Powering and Grounding Electronic Equipment).
- ITU-T K.45 (Protection of telecommunication lines using metallic conductors against lightning discharges).

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Lightning-Prone Areas and Their Impact on Infrastructure

According to data from the Meteorology, Climatology, and Geophysics Agency (BMKG), Indonesia is among the regions with high levels of lightning activity, particularly in Sumatra and Kalimantan. Lightning intensity is measured using the Isokeraunic Level (IKL), which is the number of lightning days per year. Areas with an IKL of >100 days/year are categorized as lightning-prone. Under these conditions, repeated lightning strikes can reduce equipment lifespan and disrupt the availability of fiber optic network services.

System Reliability and Performance Indicators

Reliability is the ability of a system to operate according to its intended function over a specified period of time without failure. In the context of power supply and protection systems, reliability indicators include:

- Availability (A) = MTBF / (MTBF + MTTR)
- MTBF (Mean Time Between Failures) – average operating time between failures.
- MTTR (Mean Time To Repair) – average time to repair after failure.

A high availability value indicates that the system rarely experiences downtime and is quickly restored when a disruption occurs.

METHODS

This research uses a descriptive quantitative approach, namely, this research uses a quantitative descriptive method with a case study approach. This approach was chosen to analyze the reliability of the power supply system and lightning protection in fiber optic networks based on field data, technical measurements, and statistical analysis of reliability.

RESULTS AND DISCUSSION

Infrastructure Network.

The telecommunications infrastructure owned by PT PLN was built to complement the electricity distribution system (PLN). The communications infrastructure of PT PLN (Persero) P3B, in this case the fiber optic network is managed by PT ICON+. PT PLN Telecommunications Network

- Location of North Sumatra
- Installed Capacity: 2 Gbps (STM 16)
- Used Capacity: 2 Mbps
- Idle Capacity: 1.8 Gbps

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Table 1. Infrastructure and its functions

Types of Infrastructure	Description / Function	Examples / Notes
Fiber optic	It is the backbone of data communications, used for PLN's internal needs (monitoring, control, communication between substations/generators) and also public infrastructure to support project inaugurations and external services.	• PLN Icon Plus Sumbagut conducts patrols and tidying up of fiber optic cables in Medan and the surrounding areas.Public service • The fiber optic infrastructure at the Simpang II Siantar toll exit is passed through the relocation/arrangement of FO (fiber optics) aerial cables.
Telecommunication network for special events/projects	PLN provides a communication network to support the implementation of important events or the inauguration of power plant projects so that data, broadcasts, and communications run smoothly without interruption.	During the inauguration of 26 power plants in 18 provinces, including the Asahan 3 Hydroelectric Power Plant in North Sumatra, PLN Icon Plus prepared telecommunications infrastructure so that the hybrid/inauguration activities could run smoothly.
Cable & network management and maintenance	There are mechanisms for maintenance, arrangement, and monitoring of cable reliability (including fiber), as well as standby work during certain periods (for example, Christmas and New Year) to avoid disruptions.	Fiber optic cable tidying by PLN Icon Plus Sumbagut on several roads in Medan and its surroundings to ensure the network remains stable.Public service • Relocation/sterilization of FO networks on toll roads/infrastructure development areas
Right of Way (RoW) supporting infrastructure	Poles, overhead cables, cable management areas—including space management on electricity poles for PLN's fiber cables and telecommunications	PLN Icon Plus carries out aerial FO cable relocation work, cable arrangement on electricity poles for aesthetics and network reliability.

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	infrastructure.	
Telecommunication Subholding (PLN Icon Plus)	A unit/subholding tasked with managing PLN's telecommunications assets, such as cables, fiber networks, maintenance, and provision of internal and external telecommunications services.	PLN Icon Plus Sumbagut has been mentioned several times as a party strengthening and accelerating the provision of telecommunications infrastructure in North Sumatra for new electricity projects.

Based on the available data table, several challenges related to PLN's telecommunications infrastructure in North Sumatra:

- Cables that are messy / not well arranged → need to be arranged / tidied up.Public Service+1.
- Relocation & coordination is required when other infrastructure development (e.g. toll roads) interferes with the existing network.icon.energika.id.

To maintain network reliability, especially during major events or peak communication usage, PLN is on special alert.

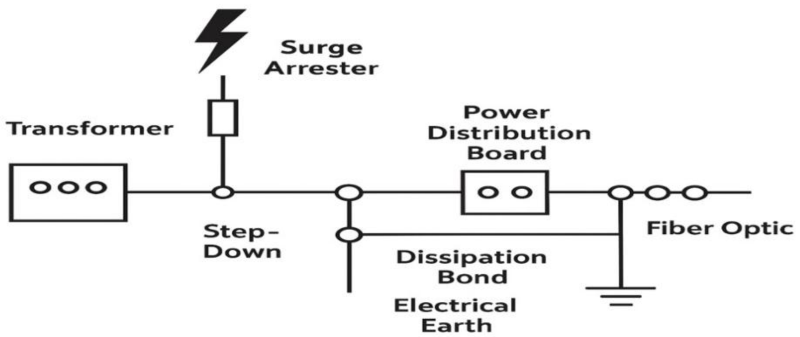

Figure 2. Experimental system schematic

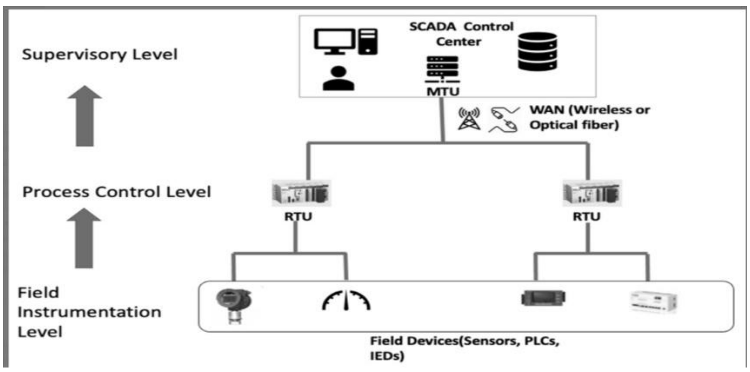

Figure 3. RTU System Algorithm

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Performance of Master Scada and 500 KV RTU

Below is the performance report data RTU starting from July 1, 2025 00:00 – August 28, 2025 11:59 PM

Table 2.RTU Performance

Region	500 KV RTU Device	Down Time	Up Time	Availability
		Hours	Hours	%
Region 1	IslandNias	2,384	669,615	99,645
	Mount Sitoli	6,391	665,609	99,049
	Deep Bay	0.014	671,986	99,998
	Tello Island	0.012	671,988	99,998
	Nine Islands	0.055	671,944	99,992

Based on the table above, it can be seen that the average downtime for all regions is quite small, namely an average of 4.76 hours per month and the average availability is above 90%. This shows that fiber optic monitoring is very reliable.

Table 3. Main Functions of RTU

Function	Information
Telemetering	Real-time measurement of electrical quantities such as current, voltage, frequency for load data collection and system stability.FlipHTML5+2How to Learn+2
Telesignal / Telesignaling	Sending device status (e.g. ON/OFF, opening/closing breaker, alarm) to the control center.How to Learn+1
Telecontrol	Control of devices in the field from the control center via RTU, for example opening/closing breakers remotely.

Reliability of the Power Supply System in Fiber Optics

Fiber optic networks require a stable power supply for active devices such as OLTs (Optical Line Terminals), ODFs (Optical Distribution Frames), and repeaters. In lightning-prone areas, electrical disturbances from lightning surges, momentary overvoltages, and transient currents can cause:

- electronic device damage,
- decrease in data transmission quality,
- telecommunications service downtime,
- high maintenance costs.

Therefore, power supply systems must be designed with reliability and resilience to lightning strikes in mind. Electrical disturbances in fiber optic networks in lightning-prone areas can originate from:

- Electromagnetic induction due to indirect lightning strikes,
- Overvoltage entering through the PLN distribution network,
- Inadequate grounding, so that the surge current is not completely dissipated,
- Failure of the protection system, for example arresters or fuses that do not meet standards.

To increase the reliability of the power supply system, several protection devices are

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used:

- Surge Arrester → protects equipment from voltage surges caused by lightning.
- Grounding System (earthing) → channels lightning current to the ground with a resistance of < 5 ohms.
- UPS (Uninterruptible Power Supply) → maintains power continuity during a short-term power outage.
- Dissipation Bond → helps dissipate surge energy to the ground.
- Circuit Breaker & Fuse → protects equipment from overcurrent.

System reliability is measured based on the probability that the system will remain functional for a specified period despite a disruption. In this context, the indicators used include:

- MTBF (Mean Time Between Failure) → the higher the MTBF value, the more reliable the system.
- Availability → the ratio of system uptime to total operational time.
- Failure Rate (λ) → frequency of damage due to lightning surges and electrical disturbances.

From simulations and literature, systems with layered protection (arresters + grounding + UPS) are able to reduce the frequency of disturbances by up to 50–70% compared to systems without additional protection.

In northern Sumatra, lightning intensity is very high (isokeraunic level > 150 lightning days/year). Without protection, transmission equipment often experiences:

- power supply module damage,
- backbone link disruption,
- data loss.

However, after installing a good surge arrester + grounding protection system, network reliability increases, downtime decreases significantly, and maintenance costs are lower.

A power supply system equipped with multi-layered lightning protection (surge arresters, grounding, UPS, and secure distribution) is crucial for maintaining the reliability of fiber optic networks in lightning-prone areas. Reliability analysis shows that implementing protection can significantly improve availability, reduce failure rates, and minimize operational downtime.

CONCLUSION

Based on the analysis, it can be concluded that the power supply and protection systems play a crucial role in maintaining the reliability of fiber optic networks, particularly in lightning-prone areas. Electrical disturbances caused by lightning strikes, whether directly or indirectly, have the potential to damage active devices, reduce service quality, and increase operational downtime. The implementation of a layered protection system, including surge arresters, low-resistance grounding systems, UPSs, and overcurrent protection devices, has been shown to improve system reliability. This is reflected in a reduced failure rate, increased Mean Time Between Failure (MTBF) values, and reduced service downtime by up to 50–70% compared to systems without protection. With this increased reliability, the quality of service (Quality of Service/QoS) of fiber optic networks is more assured, maintenance costs can be reduced, and the sustainability of telecommunications services in lightning-prone areas can be maintained. Therefore, the design of a reliable power supply system and adequate protection are crucial

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aspects that must be considered in the development of modern telecommunications infrastructure.

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