Technical Feasibility Analysis of the 500 kV Extra High Voltage Overhead Transmission System Project in Sumatra

Trisno Dharma Putra [1,2], Kevin Marojahan Banjar-Nahor[1] & Nanang Hariyanto [2]

[1] School of Electrical Engineering and Informatics, Institut Teknologi Bandung
[2] PT PLN (Persero)
Email: 23222379@mahasiswa.itb.ac.id

Abstract The 500 kV Extra High Voltage Transmission Line project in Sumatra is a critical infrastructure initiative designed to improve the efficiency and reliability of power transmission across the island. This study evaluates the technical feasibility of the project by analyzing key aspects such as operational efficiency, structural integrity, and environmental impact. The project aims to address growing energy demands in Sumatra while resolving bottlenecks in the existing 275 kV transmission system. It also facilitates the integration of renewable energy sources, such as geothermal and hydroelectric power, into the grid, contributing to a reduced reliance on fossil fuels and supporting Indonesia's transition toward sustainable energy. The findings suggest that the project will significantly enhance the stability of the Sumatra power grid, optimize energy distribution, and promote environmental sustainability. Overall, the project is deemed feasible and essential for securing the region's long-term energy needs.

Keywords: *Index Terms—500 kV Transmission Line, Feasibility Study, Electricity Market Optimization*

1. Introduction

The construction of the 500 kV transmission system in Sumatra represents a significant milestone in Indonesia's power infrastructure development. This initiative primarily addresses inefficiencies in the energy distribution network and the rising integration of renewable energy sources into the grid. The project forms part of Indonesia's long-term strategy to improve the reliability and stability of its power networks, particularly given the increasing demand for electricity and the need to diversify its energy mix.

Sumatra, endowed with significant renewable energy re- sources such as geothermal and hydropower, has the potential to shift its energy mix away from a reliance on fossil fuels. The Indonesian government has initiated several programs, such as the fast-track renewable energy program, to increase renewable

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capacities and reduce greenhouse gas emissions. The integra- tion of the 500 kV transmission system is expected to facilitate the efficient transport of electricity generated from renewable sources over long distances, which is crucial in managing the fluctuating nature of renewable energy generation [1].

EHV transmission lines are essential for the effective trans- mission of substantial quantities of electrical power over long distances. Key operational characteristics, including corona losses and state estimation methodologies, are pivotal in maintaining system reliability and operational efficiency. The modeling and understanding of corona-loss characteristics, for instance, are critical because they directly impact the operational performance of EHV lines [2]. Additionally, incor- porating controlled series compensators can further enhance power flow management, thereby increasing the transmission system's overall efficiency [3].

In recent years, advancements in transmission system com- ponents, particularly high-voltage direct current (HVDC) sys- tems, have opened new avenues for enhancing transmission efficiency. HVDC systems are increasingly preferred for con- necting renewable energy sources, such as offshore wind farms, to the grid with minimal transmission losses [4] [5]. Voltage-source converters (VSCs) for HVDC systems allow greater penetration of wind energy and serve as an efficient alternative to traditional extra-high-voltage alternating current (EHV AC) transmission lines [6] [7]. Developments in gas- insulated switchgear also play a critical role in ensuring the safety and efficiency of high-voltage devices [8].

On of the methods of increasing the transmission line capability is voltage uprating which is a key method. It was discovered from the research studies that voltage uprating remains relatively cheap as well as more efficient in terms of time as opposed to the construction of new transmission lines. Different methods like the re-insulation and recon- ductoring have been applied in other parts of other regions thus transforming low voltage systems to 275 kV through new infrastructure [9] [10]. For instance, revealed that it is possible to retrofit existing 132kV lines to 275kV power transmission level without compromising electrical clearance standards that are very important in ensuring reliable and safe power transmission system [9].

In addition, the geophysical and climate conditions occur- ring within Sumatra present unique challenges, particularly regarding corona power losses in high humidity conditions. Research of the effect of tropical climate factors discussed transmission efficiency and noted that air movement, temper- ature and humidity all play a significant role in corona losses in the transmissibility of 275 kV lines [11]. Addressing these losses through design modifications or operational adjustments could enhance the overall efficiency of the transmission sys- tem.

In summary, addressing the 275 kV transmission system bottlenecks in Sumatra will require several approaches, in- cluding voltage uprating, combating climatic challenges, em- bracing renewable energy systems, and leveraging advanced transmission technologies. This multi-faceted strategy will enable the more efficient use of inexpensive energy sources, ensuring a more reliable and sustainable power supply across Sumatra.

2. Problem Formulation

On March 19, 2024, there was a substantial increase in electricity usage on the island of Sumatra, which is crucial for Indonesia's energy infrastructure (refer to Figure 1). At 7:30 PM Western Indonesia Time (WIB), the peak power demand reached an impressive 7,283 megawatts (MW). This increase highlights the escalating energy demands of Suma- tra's swiftly expanding population and businesses. Coal, an essential component of Indonesia's energy portfolio, remained the predominant source of power generation, accounting for almost 47.

The fluctuations in electricity demand in Sumatra corre- sponded to the daily rhythm of life. As the sun rose, energy consumption gradually increased as a result of the actions of households and businesses. The greatest amount of demand was seen during the late afternoon and evening, coinciding with the pinnacle of business operations and increased house- hold electricity consumption.

Sumatra's energy industry faces challenges and opportu- nities in meeting a peak power demand of 7,283 MW. It primarily stresses the importance of continuous investments in capacity for power generation to meet the increasing demand; however, it stresses the need to diversity the inventories of energy sources, meaning a reduced reliance on coal, and minimize climate change risks.

It essentially highlights the significance of ongoing invest- ments in capacity for the generation of power to respond to the growing demand, while underscoring the importance of diversity in energy inventories (less dependency on coal), and mitigates overall climate change risks.

3. Proposed Method

The load center of Sumatra is based on the topology in the Northern Sumatra Subsystem (NSS). As opposed, the cheap generation centers include mine mouth and wellhead which are located in Central and Southern Sumatra Subsystems (CSSS). According to the power dynamics of the Sumatra Bangka System outlined in the RUPTL edition for 2024 – 2033 released in February 2024;

projections suggest a potential 5,89% increase in electricity sales and a projected growth of about 4,8% in peak load, over the same period.

This research focuses on developing a feasibility study with the solution :Construction of the 500 kV Extra High Voltage Transmission Line in Sumatra.

A. Existing Condition

From the Table I, the installed capacity of Interbus Trans- formers (IBT) at several Extra High Voltage Substations (EHV Substation) throughout the Sumatra region, specifically in the 275 kV and 500 kV transmission lines. The capacity of an Inter-Bus Transformer (IBT) plays a vital role in ensuring the reliability of energy transfer between various voltage levels, especially in transmission networks that operate at very high voltages. Installed capacity is the highest capacity of the IBT to manage electrical loads, measured in megavolt-amperes (MVA).

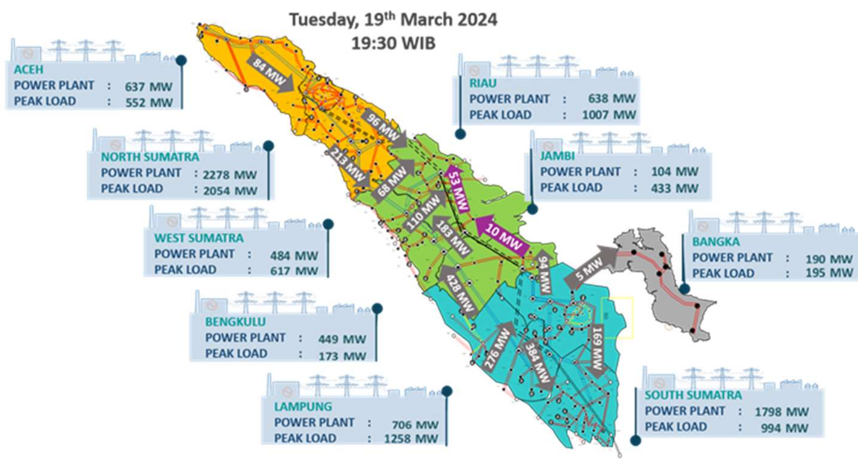
TABLE I
INSTALLED CAPACITY OF INTERBUS TRANSFORMERS

EHV Substation	UNIT	Voltage (kV)	MVA
Galang 275kV	#1	275/165	166.7
		275/165	166.7
		275/165	166.7
	#2	275/165	166.7
		275/165	166.7
		275/165	166.7
Perawang 275kV	#1	275/165	83.33
		275/165	83.33
		275/165	83.33
	#2	275/165	83.33
		275/165	83.33
		275/165	83.33
Perawang 500kV	#1	500/275	166.7
		500/275	166.7
		500/275	166.7
New Aur Duri 275kV	#1	275/165	83.33
		275/165	83.33
		275/165	83.33
	#2	275/165	83.33
		275/165	83.33
		275/165	83.33

New Aur Duri 500kV	#1	500/275	167
		500/275	167
		500/275	167

B. Potential Risk

The potential risk impacts if the 500 kV Extra High Voltage Transmission Line (Extra High Voltage Transmission Line) project in Sumatra is not implemented are as follows:



- Bottlenecking will occur in the 150 kV and 275 kV transmission lines in the Central and Southern Sumatra subsystems.
- The Sumatra Generation Cost (BPP) is expected to in- crease by Rp3.04/kWh in 2026 and by Rp4.32/kWh in 2028.

4. Results

A. Analysis of Power Flow Conditions Before and After Project Options

Before the 500 kV Sumatera Line (EHV 500 kV Muara Enim – New Aur Duri) starts operating in 2026 which shown in Figure 2, the voltage levels at substations comply with the criteria of the Grid Code as specified in Permen ESDM No. 20 of 2020. This control allows for voltage fluctuations of plus or minus 5 percent at both 500 kilovolts and 275 kilovolts. In addition, the transmission loading in the project region meets the N-1 standard, which requires that the loading be below 51%. However, the absence of the 500 kV Sumatera line will hinder the effective transfer of affordable electricity from the Southern and Central

Sumatera subsystem (CSSS) to the Northern Sumatera subsystem (NSS). The inefficiency is caused by bottlenecks in the 275 kV transmission network on the West Sumatera side, which has restrictions in multiple portions.

Once the 500 kV Sumatera Line is finished in 2026, it will guarantee that the voltage levels at substations adhere to the standards specified in the Grid Code. The capacity of the MT Sumsel-8 coal-fired power station can be increased from 2x480 MW to 2x600 MW.The transmission loads will consistently adhere to the N-1 criterion, guaranteeing unin- terrupted operational stability. By the time 2028 arrives, the EHV 500 kV Perawang - Rantau Prapat - Galang power line and other similar lines will be in service. This will ensure that the voltage levels at substations meet the requirements stated in the Grid Code. The transmission loading in the vicinity of the project will remain within the N-1 level. To effectively manage the elevated voltage that arises during both switching and continuous operation, particularly over extended distances, it will be imperative to deploy supplementary reactors at the EHV Substation 500 kV substations.

Table II provides a comparative overview of the voltage levels at various substations before and after adjustments for the year 2026. The data reveals that the voltage in kilovolts (kV) and per unit (pu) values for each substation have been analyzed. For example, at the Sumsel-8 substation, the voltage increased from 502.6 kV to 507.9 kV, with the per unit value shifting from 1.00 to 1.01. Similarly, Muara Enim’s 500 kV voltage rose from 502.3 kV to 509.7 kV, and its per unit value also went from 1.00 to 1.01. In the case of Muara Enim’s 275 kV voltage, there was an increase from 277.2 kV to 281.6 kV, with the per unit value adjusting from 1.00 to 1.02. The New Aur Duri substation saw a significant rise in voltage from 500.1 kV to 512.4 kV, accompanied by a per unit value increase from 1.00 to 1.02. The Peranap substation had a slight voltage increase from 500.6 kV to 506.1 kV, however the per unit value remained relatively constant at 1.01. This research outlines the expected voltage fluctuations and changes across multiple substations throughout the specified period

TABLE II
VOLTAGE ANALYSIS OF SUBSTATIONS IN 2026

Substation	Voltage (kV)	Unit	2026 Before	2026 After
Sumsel-8	500 kV	kV	502.6	507.9
		pu	1.00	1.01
Muara Enim	500 kV	kV	502.3	509.7
		pu	1.00	1.01
Muara Enim	275 kV	kV	277.2	281.6

		pu	1.00	1.02
New Aur Duri	500 kV	kV	500.1	512.4
		pu	1.00	1.02
Peranap	500 kV	kV	500.6	506.1
		pu	1.00	1.01

Table III provides a detailed examination of the transmission load across various network segments before and after the suggested improvements. The data is classified into two main categories: power measured in megawatts (MW) and percent- age values representing the load capacity of transmission lines linking critical substations.

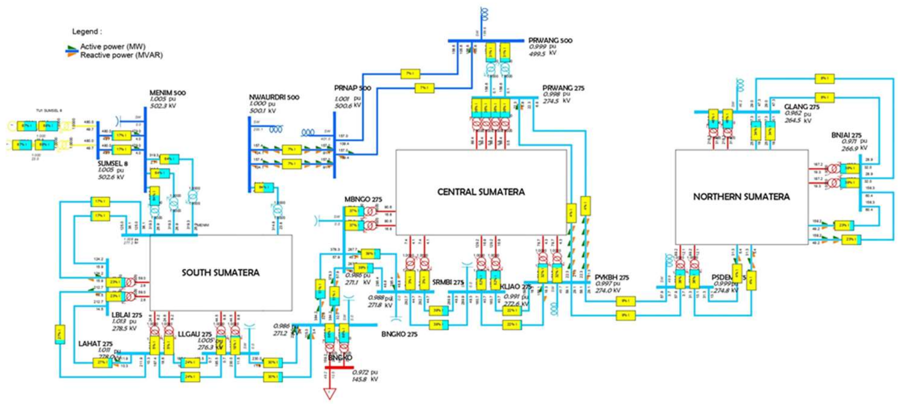


Fig. 2. Power Flow in 2026 When the 500 kV Muara Enim – New Aur Duri High-Voltage Transmission Line Has Not Yet Operated

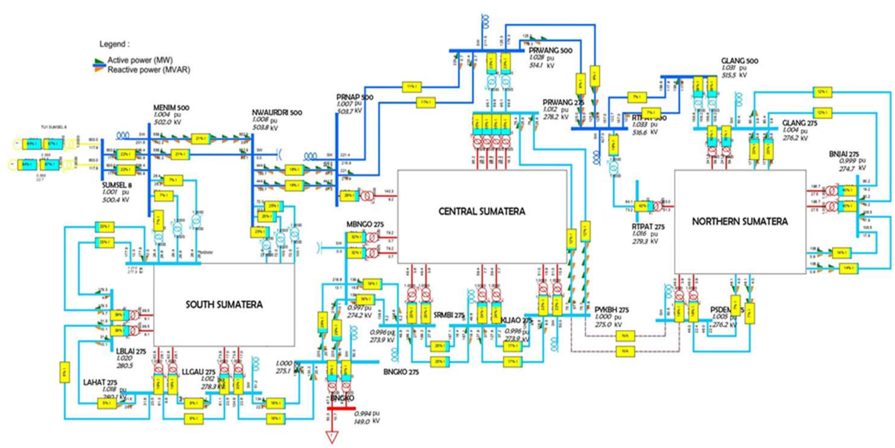


Fig. 3. Power Flow in 2028 When the 500 kV Muara Enim – New Aur Duri High-Voltage Transmission Line Is Already Operating

Furthermore, the data for the year 2028 can be seen in Figure 3. Regarding the substation voltage in the project, all substation voltages comply with the criteria set by the Grid Code (Ministry of Energy and Mineral Resources Regulation No. 20 of 2020 on the Grid Code for the Electric Power System). The permissible voltage limits for 500 kV and 275 kV are +5% and -5%. Regarding the transmission loading near the project, all conductors meet the N-1 requirement, meaning that their loading is above 51%.

B. Feasibility study of operations

In summary, the implementation of the 500 kV Sumatera Transmission Line is expected to significantly improve the efficiency of energy transmission from CSSS to NSS and in- creased reliability. However, it is essential to carefully evaluate several risks at each stage of the project to ensure a successful outcome and operation.

The analysis conducted aims to assess the electrical con- ditions around the 500 kV Extra High Voltage Transmission Line project in Sumatra. The assumptions used in the power flow study are as follows:

TABLE III
TRANSMISSION LOAD ANALYSIS FOR THE YEAR 2026

From to	(kV)	2026 Before	2026 After
Sumsel-8 to Muara Enim	500 MW	2x480	2x600
Sumsel-8 to Muara Enim	500%	2x17	2x22
Muara Enim to New Aur Duri	500 MW	-	2x398
Muara Enim to New Aur Duri	500 %	-	2x15
New Aur Duri to Peranap	500 MW	2x157.4	2x359.2
New Aur Duri to Peranap	500 %	2x7	2x13

- The 500 kV Extra High Voltage Transmission Line Muara Enim – New Aur Duri will be operational in 2026.
- The 500 kV Extra High Voltage Transmission Line Per- awang – Rantau Prapat, along with the associated 500 kV substations, will be operational in 2028.

- The 500 kV Extra High Voltage Transmission Line Rantau Prapat – Galang, along with the associated 500 kV substations, will be operational in 2028.
- Simulations are carried out for the period from 2026 to 2033 during peak load times.
- The Sumatra system's loading is based on substation ca- pacity according to the draft RUPTL 2024–2033, October 2023 version.
- Transmission development projects (new and reconduc- toring), new substations, and transformers (new, uprat- ing, or extension) will operate as per the draft RUPTL 2024–2033, October 2023 version.
- The new power plants in the Sumatra system will operate according to the Sumatra-Bangka power balance draft for 2024–2033, February 2024 version.
- Power plants in the Sumatra system will operate accord- ing to the merit order.

C. Transient Stability Analysis

The purpose of transient stability analysis is to observe the impact of a three-phase short circuit fault in the network surrounding the 500 kV High Voltage Transmission Line (EHV) in Sumatra. The assumption is that a three-phase short circuit occurs in the network near the project area, as follows:

1) Circuit 1 of 500 kV EHV Muara Enim – New Aur Duri Assumption: A three-phase short circuit occurs on Cir- cuit 1 of the 500 kV EHV Muara Enim – New Aur Duri at the 3rd second. The circuit trips and recloses at 3.09 seconds. The Figure 4 shows the voltage response at EHV Substation 500 kV Muara Enim.

2) Circuit 1 of 500 kV EHV Perawang – Rantau Prapat Assumption: A three-phase short circuit occurs on Cir- cuit 1 of the 500 kV EHV Perawang – Rantau Prapat at the 3rd second. The circuit trips and recloses at 3.09

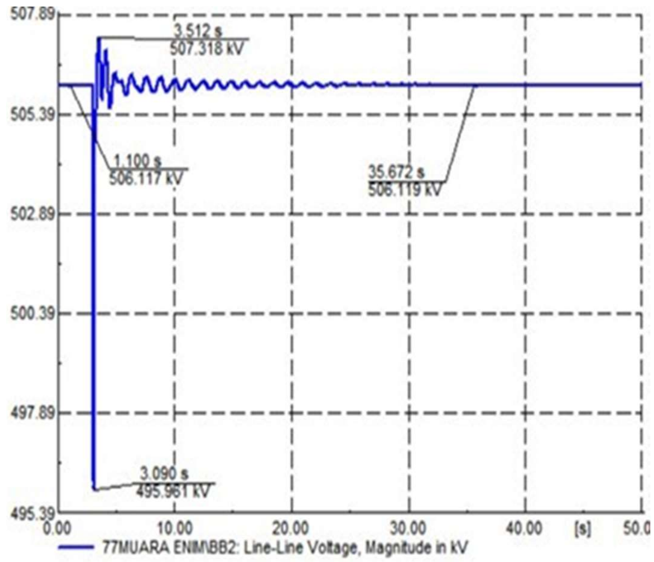


Fig. 4. Voltage Response at EHV Substation 500 kV Muara Enim during the 3-phase fault on the 500 kV EHV Muara Enim – New Aur Duri (Reclose)

seconds. The Figure 5 shows the voltage response at EHV Substation 500 kV Rantau Prapat:

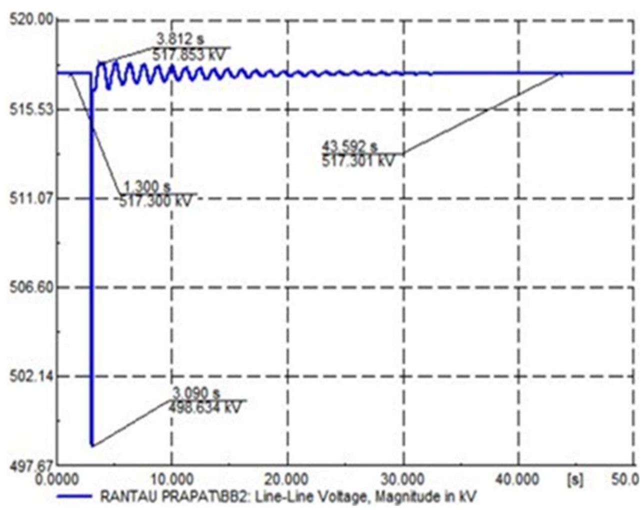


Fig. 5. Voltage Response at EHV Substation 500 kV Rantau Prapat during the 3-phase fault on the 500 kV EHV Perawang – Rantau Prapat (Reclose)

3) Circuit 1 of 500 kV EHV Rantau Prapat – Galang Assumption: A three-phase short circuit occurs on Cir- cuit 1 of the 500 kV EHV Rantau Prapat – Galang at the 3rd second. The circuit trips and recloses at 3.09 seconds. The Figure 6 shows the voltage response at EHV Substation 500 kV Galang.

   Based on the transient stability analysis for the three-phase short circuit fault on Circuit 1 of the 500 kV EHV Muara Enim – New Aur Duri, Circuit 1 of the 500 kV EHV Perawang – Rantau Prapat, and Circuit 1 of the 500 kV EHV Rantau Prapat – Galang (with trip at 3 seconds and reclose at 3.09 seconds), the voltages at EHV Substation 500 kV Muara Enim, EHV Substation 500 kV Rantau Prapat, and EHV Substation 500 kV Galang return to normal (stable) conditions:

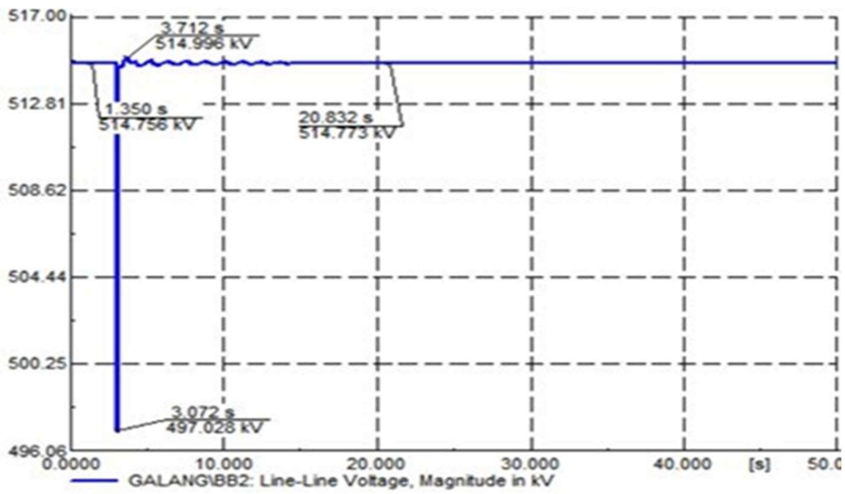


Fig. 6. Voltage Response at EHV Substation 500 kV Galang during the 3- phase fault on the 500 kV EHV Rantau Prapat – Galang (Reclose)

TABLE IV
COMPARISON BETWEEN 275 KV AND 500 KV EXPANSION

Description	**275 kV Expansion**		**500 kV Expansion**	
	Total Substation within limits	**Score**	**Total Substation within limits**	**Score**
Voltage 0.90 - 1.05	8 out of 13	0.615	13 out of 13	1
Loading < 80%	12 out of 13	0.923	13 out of 13	0.955

Short Circuit < 40kA	13 out of 13	1	13 out of 13	1
Frequency Nadir	49.5 Hz	0.5	49.6 Hz	0.6
Total	3.038		3.600	

The evaluation of EHV 500 kV Sumatera is based on three fundamental parameters: Load Flow, Short Circuit, and Stability (see Table IV). These parameters are crucial in assessing the performance, reliability, and safety of a technical system, particularly in the context of electrical or control systems. The analysis presented shows that 500 kV High Voltage Transmission Line (EHV) in Sumatra satisfies the key requirements, making it eligible for further consideration.

5. Conclusion

The strategic placement of the 500 kV Extra High Voltage Transmission Line is designed to significantly enhance the efficiency of power transmission across Sumatra. To ensure reliable and consistent energy supply, it is essential to address the current limitations within the network. This will particu- larly improve the transmission of power from the Southern and Central Sumatra subsystems to the Northern Sumatra subsys- tem. Overcoming these limitations is critical to maintaining a stable and resilient energy supply. The deployment of 500 kV transmission lines will ensure that substation voltage levels remain within the limits outlined in the Grid Code, which permits a tolerance of ±5% from the target value. Additionally, the transmission loads will meet the N-1 standard, ensuring operational stability and efficiency throughout the network. The project's impact includes improving both the capacity and reliability of the grid. By 2028, when the 500 kV lines are fully operational, they will effectively manage higher voltage levels and increase the capacity of power stations. In conclusion, the 500 kV Extra High Voltage Transmission Line project is expected to enhance the reliability, functionality, and efficiency of Sumatra's electrical system. The project has been carefully planned to achieve its objectives and deliver long- term benefits to the energy sector in Sumatra through diligent risk management. Based on the operational feasibility study, it can be concluded that the construction of the 500 kV Extra High Voltage Transmission Line in Sumatra is both feasible and beneficial.

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