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Performance Optimization Analysis of a 20 Kilo Volt (kV) Distribution Network in Dili City Using ETAP Software

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Abstract

The 20 kV power distribution network in Dili City faces technical challenges in the form of voltage drop and relatively high feeder loading levels, particularly on feeders with long distribution routes. The Dili City distribution network has a configuration centralized to a single power supply source, namely the Camea Substation, which limits the ability to transfer loads. This research aims to analyze the existing condition and to evaluate the effect of adding a new substation in the Comoro area on improving network performance. This research uses a power flow simulation–based approach employing ETAP software. The results show that under existing conditions, buses at the end of the lines experience voltage drops below the allowable standard of up to 14.30%, and four feeders have loading levels exceeding 75%. The addition of the Comoro Substation and network reconfiguration significantly improve the voltage profiles of the distribution system, ensuring compliance with SPLN 72:1987. The loading level of the Camea Substation decreases to 72% of its capacity due to the reduction of feeder load, increasing the capability for load transfer and accommodating future load growth.

Keywords: *Distribution Network, ETAP, Feeder Loading, Substation, Voltage Drop*

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1. Introduction

Based on a report from PT. EDTL (2021), the performance of the 20kV distribution network in Dili City has been unsatisfactory due to the high load on the 20kV feeder. Power outages occur frequently, directly impacting community activities and the local economy and resulting in poor SAIDI and SAIFI indices. Data from PT. EDTL in 2024 shows that the SAIDI value of the 20kV distribution system in the Dili area reached 1774.9 hours/customer/year and the SAIFI value reached

124.3 times/customer/year. Based on SPLN 68-2:1986, the standard reliability index for SAIDI is 15.36 hours/customer/year, while SAIFI is 2.88 times/customer/year [1]. These disruptions were caused by a number of key factors, including a significant increase in peak load due to the growth in daily electricity consumption, which limited the network's load transfer capacity [2].

The distribution network in Dili City is supplied from the Camea substation, which is approaching its maximum capacity of 63 MVA, and several 20kV medium voltage feeders are loaded at more than 80% of their capacity. There is no nearby substation for load transfer in an emergency. Data shows that the distribution network often experiences voltage drops of up to 14.30% at the end of medium voltage lines, which cannot be compensated by transformer load taps. Meanwhile, the voltage drop standard based on SPLN No. 72 of 1987 is +5% and -10% of the nominal voltage [3]. This voltage drop can impact network efficiency due to high line power losses [4].

As the city of Dili, the capital of Timor-Leste, develops and expands to the west, more than 20% of the population lives in Dili City. Access to the city's electricity supply is served by six 20kV medium voltage distribution feeders from the Camea Substation located at the eastern end of the city. The greatest demand for supply is on the western side of the city. Therefore, it is necessary to investigate the status of the medium voltage distribution system in Dili City, including substation load, feeder load, and voltage profile. One of the technical solutions commonly applied to overcome problems of power loss, voltage drop, and overload is the addition of a new substation [5], [6].

Determining the optimal location for substations is very important in order to cope with the growth in electrical load and support the sustainability of the power system [7]. Currently, the use of data-based reliability analysis methods and computer simulations using ETAP software has been proven to provide an in-depth picture of vulnerable points and potential improvements in the distribution system [8]. ETAP, or Electrical Transient Analyzer Program, is power system analysis software designed to model, simulate, and evaluate power system performance under steady-state and transient operating conditions [6], [8]. A study [4] used ETAP to analyze voltage drops in the 20 kV distribution network of PT PLN (Persero) UP3 Banda Aceh and showed a detailed picture of the voltage profile and load conditions on each feeder. ETAP software was also used by [9] to analyze the effect of network maneuvers on power losses and feeder loading in medium voltage distribution systems.

This study uses a power flow simulation-based approach using ETAP software to assess the effect of adding a new substation on improving the performance and reliability of the 20kV electrical distribution system in Dili City. Urban development and westward expansion of Dili City have increased the demand for electricity supply, leading to the planned installation of a new substation in the western area. ETAP software was chosen because it can realistically model networks through single line diagrams and quantitatively calculate technical parameters such as voltage profiles, power losses, and equipment loading [4], [5], [8]. By comparing the simulation results of the existing conditions and the substation addition scenario, this study is expected to provide a clear technical picture of the effectiveness of adding substations in improving the overall performance of the 20kV distribution network in Dili City.

2. Methods

The stages of modeling the 20kV distribution network simulation in Dili City using ETAP software follow the flowchart in **Figure 1**.

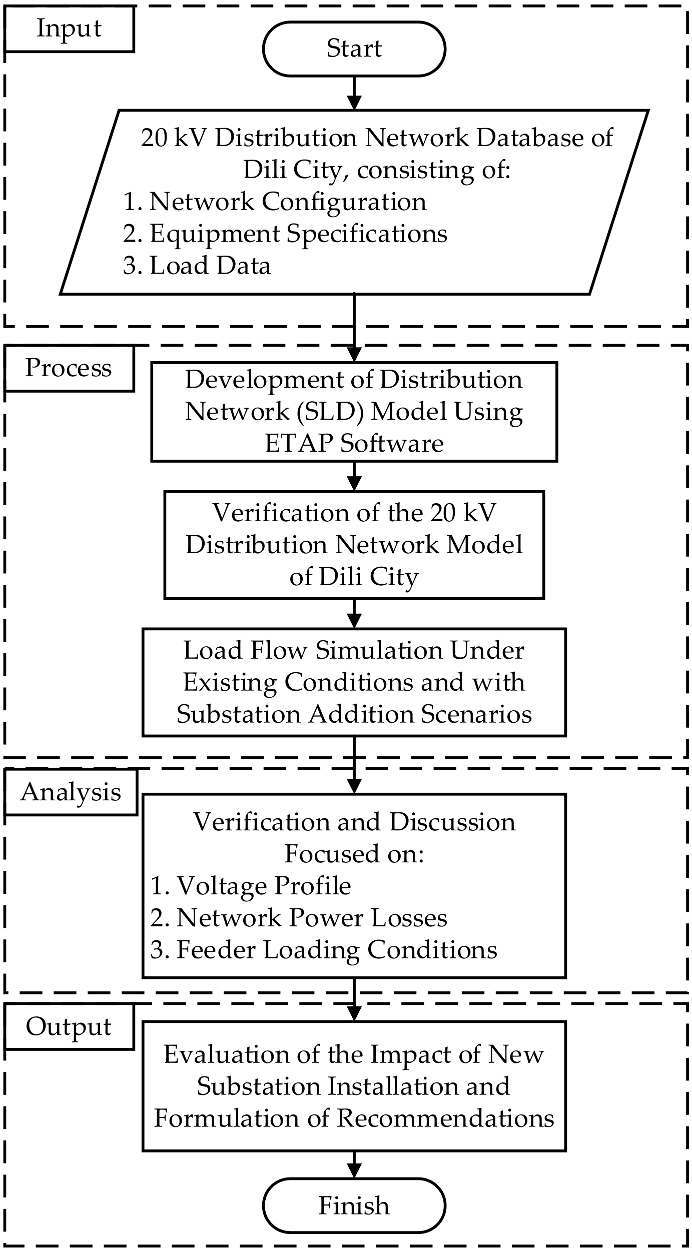

Figure 1. ETAP Modelling Flowchart of Dili City Distribution Network

Based on the diagram in Figure 1, the 20 kV distribution network database of Dili City, including network configuration, equipment specifications, and loading data, was prepared as the basis for simulation modeling. The simulation model was developed using ETAP software and subsequently verified to ensure consistency with the existing operating conditions of the 20 kV distribution system in Dili City. The verification process included validation of network configuration, equipment specifications, and load data against the available database. This step was essential to ensure that the simulation model accurately represented the actual distribution network conditions.

The verified model was then analyzed using load flow simulation under existing conditions to evaluate network performance, focusing on key technical parameters such as voltage profiles, network power losses, and feeder loading. Subsequently, a new substation was integrated into the simulation model at a critical location identified from the existing condition evaluation. Network reconfiguration was performed on feeders experiencing performance issues. The updated model, incorporating substation addition and network reconfiguration, was further analyzed using load flow simulation to assess the impact of the proposed modifications, with emphasis on voltage profiles, power losses, and feeder loading. The simulation results provided the basis for conclusions and recommendations to support scientific decision-making in distribution network planning and development, aiming to identify the most technically optimal solution and to support future infrastructure expansion planning.

2.1 Specifications of Feeder Conductors for Dili City Distribution Network

This study uses data on the 20 kV medium voltage distribution network in Dili City obtained from a single line diagram (SLD) and technical network data covering feeder configuration, conductor type and size, line length, transformer capacity, and load data for each feeder. The type, size, and length of cables for each feeder at the Camea Substation in the Dili City distribution network are provided in Table 1.

Table 1. Conductor specifications for the Dili City Distribution Network feeder

No	Feeder Number	Cable Type	Cable Size	Cable Length
1	I	AAACS	1x150mm^2	54,836 KMS
2	II	AAACS	1x150mm^2	49,703 KMS
3	III	AAACS	1x150mm^2	14,804 KMS
4	IV	AAACS	1x150mm^2	12,611 KMS
5	V	AAACS	1x150mm^2	22,735 KMS
6	VI	AAACS	1x150mm^2	23,351 KMS

2.2 Data on Feeder Loading of The Dili City Distribution Network

Load data is expressed in terms of current, active power, and reactive power. This data represents the actual conditions of the 20 kV distribution network in Dili City at the time of the study and is used as the basis for system modeling. The reference day is set for Monday, October 27, 2025. The load values refer to the current values measured at the Camea substation, which were recorded every hour during the reference day to determine the peak hours. The load graphs for each feeder of the Camea substation during the reference day are shown in **Figure 2**.

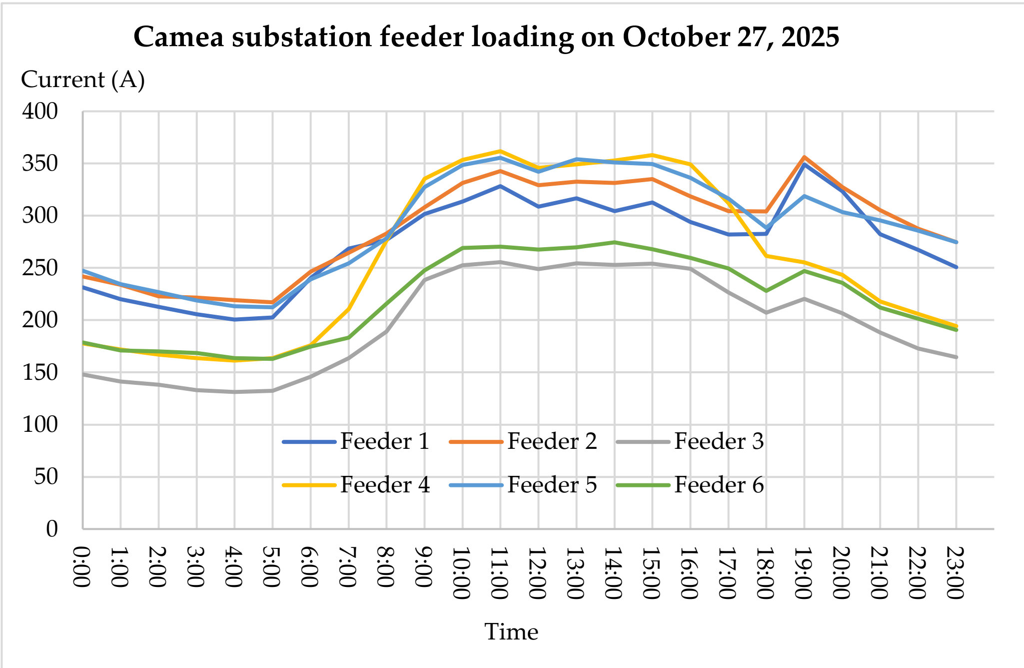

Figure 2. Feeder loading graph at Camea substation on reference day

Based on the load graph of the Camea substation feeder in **Figure 2Error! Reference source not found.**, the majority of feeders experience peak loads at 11:00 a.m. This is indicated by the high current values of each feeder at that time. Therefore, the reference date and time used for ETAP simulation modeling in this study was set at October 27, 2025, at 11:00 a.m.

2.3 Electric Transient Analysis Program (ETAP) Software

The Electrical Transient Analyzer Program (ETAP) is electrical power system analysis software designed to model, simulate, and evaluate the performance of power systems under steady-state and transient operating conditions. Modeling in ETAP software is based on single line diagrams (SLDs), which allow users to visually represent electrical power networks and perform various technical analyses, such as load flow analysis, short circuit, and protection coordination [6], [8].

In power flow analysis, ETAP uses numerical methods to solve nonlinear power system equations so that it can calculate voltage profiles, line currents, active and reactive power, and power losses at each network element [10]. Load flow simulation in ETAP supports various calculation methods and is capable of analyzing radial and loop distribution systems under normal operating conditions [8]. Voltage profiles in ETAP load flow simulations can be identified at each bus or node in the 20kV distribution network to evaluate the voltage drop value at each bus or node. In addition, the load distribution on each feeder can be identified using power flow simulations that display the current and power values flowing through the feeder.

The use of ETAP in 20 kV distribution network analysis has been widely applied in academic research. Research [4] used ETAP to analyze voltage drops in the 20 kV distribution network of PT PLN (Persero) UP3 Banda Aceh and showed that ETAP simulations were able to provide a detailed picture of the voltage profile and load conditions on each feeder. Research [9] utilized ETAP to analyze the effect of network maneuvers on power loss and feeder loading in medium voltage distribution systems. Research [11] showed that ETAP-based simulations can be used to evaluate equipment loading and system efficiency after network structure changes, thereby supporting objective and measurable technical decision making. Based on these capabilities, ETAP was selected as the main software in this study because it is capable of comprehensively modeling the 20 kV distribution network in Dili City, analyzing existing conditions through power flow simulations, and evaluating the technical impact of adding a new substation on voltage profiles, loading, and power losses.

2.4 Load Flow Analysis

Load flow analysis is a computational method used to calculate the distribution of electric current, voltage, active power, reactive power, and power losses in an electrical power system [4]. The main purpose of power flow analysis is to obtain an overview of the voltage values at each bus, the current magnitude in the lines, and the power distribution throughout the network to ensure that the system meets electrical power system standards. This analysis is very important in the planning and operation of distribution networks because it is directly related to the technical performance of the network [12].

In practice, power flow simulation can be performed using various numerical methods, such as the Gauss-Seidel method, Newton-Raphson method, and Fast Decoupled method [12]. Although the Newton-Raphson method is more commonly used in power distribution systems, ETAP software has adapted a calculation method suitable for radial distribution systems, so that simulation results remain accurate and convergent [8]. The selection of this method allows for efficient system analysis even though the network has many buses and load variations. Power flow simulation is performed by solving nonlinear equations that represent the power balance of each bus in the power system. Each bus is defined based on its type, namely slack bus, PV bus, and PQ bus [12].

Research [8] shows that load flow analysis can be used to measure bus voltage, feeder current, and total power loss, which form the basis for evaluating network performance and planning modifications to the electrical network configuration. In addition, power flow simulation is also used to identify parts of the network that are experiencing high loads or are approaching nominal capacity, which can form the basis for planning network reinforcement or development [13]. Power flow simulation also enables the calculation of power losses in distribution networks, which generally occur due to line resistance and current flowing in conductors. High power losses indicate low system efficiency and have a direct implication on increased operating costs [14].

2.5 Voltage Profile and Voltage Drop

Voltage profile is the variation in voltage values along the distribution network at each point (bus). This variation in voltage values reflects how voltage changes due to line characteristics, load size, and network configuration [4]. Voltage drop is the phenomenon of voltage reduction from the initial value at the substation to the end of the feeder due to line resistance and reactance as well as load. Research from [4] shows that line length and load current have a direct correlation with an increase in voltage drop in 20 kV distribution networks, which has the potential to reduce voltage quality on the customer side. Voltage profile analysis is very important because non-standard voltages can have a negative impact on electrical equipment performance and service quality [9]. Therefore, a technical evaluation is required to determine whether power distribution is within the permissible voltage tolerance limits. The standard used to evaluate voltage drop values in distribution networks is SPLN No. 72 of 1987, which is +5% and -10% of the nominal voltage [3].

2.6 Feeder Loading and Power Losses in the Distribution Network

Feeders serve as the main channels that distribute electrical power from substations to various load points, so that their load levels directly affect the technical performance and reliability of the distribution system [14]. Feeder loads are generally expressed in terms of electrical current (A), active power (kW), and the percentage of utilization relative to the nominal capacity of the conductors or protection equipment used. Feeder loading is closely related to the Current Carrying Capacity of the conductors used in the distribution network. Current Carrying Capacity is the maximum limit of electrical current that can be continuously carried by a conductor.

Current Carrying Capacity is determined by several factors, including the type of conductor material, conductor cross-sectional area, type of insulation, installation conditions, and ambient temperature. If the feeder load causes the current to flow close to or exceed the Current Carrying Capacity, the conductor temperature will increase significantly. This condition can accelerate insulation degradation, reduce the technical life of the conductor, and increase the risk of system disruption or failure [15]. The Current Carrying Capacity of conductors based on SPLN 41-10:1991 is shown in Table 2.

Table 2. Current Carrying Capacity of sheathed conductors AAAC-S

Conductor Types	Conductor Size	Current Carrying Capacity at Ambient Temperature	
		30°C	40°C
AAAC-S	70 mm²	275 A	246 A
AAAC-S	95 mm²	315 A	282 A
AAAC-S	120 mm²	356 A	319 A
AAAC-S	150 mm²	423 A	378 A
AAAC-S	180 mm²	484 A	423 A
AAAC-S	240 mm²	586 A	532 A

Power losses in electrical power distribution networks are the difference between the power supplied from the source and the power received by the load. Power losses technically occur due to the resistance and reactance of conductors, which cause some of the electrical energy to be dissipated in the form of heat. The amount of power loss in distribution networks is influenced by several main factors, including the length of the line, the cross-sectional area of the conductor, the load current, and the network configuration. A study by [4] proves that reducing current through network structure improvements, such as load sharing or shortening the length of the feeder, can effectively reduce power losses in a 20 kV distribution system.

3.Results and Discussion

3.1 Existing Condition of the Distribution Network in Dili City

Based on the results of load flow simulations under existing conditions, the performance of the 20 kV distribution network in Dili City still faces several technical problems related to voltage profiles and feeder loading that do not allow for load transfer during emergency conditions. The structure of the 20 kV distribution network in Dili City has radial system characteristics with relatively long feeders and high feeder loading levels. Feeders at the Camea Substation experience voltage drops at the end of the line that exceed the permitted standard values, reaching 14.30% at the end of the line in feeder 1 and 10.92% at the end of the line in feeder 2.

From a load aspect, there are four feeders that have a load percentage of more than 75% of their capacity. Feeder 4 is the feeder with the highest load level, reaching 85.51% of its nominal capacity. This problem is due to the limitations of the network configuration, which is still centered on a single supply source, namely the Camea

Substation. Without a new substation to supply voltage closer to the load center, the current that must be carried by the feeder at the Camea Substation will remain high and affect the voltage drop and power loss in the line. High loading causes an increase in power loss due to the large amount of current flowing through the conductor. The results of this analysis of existing conditions provide strong technical justification for the need to add a new substation. The location of the new substation in this study was determined to be in the Comoro area.

Table 3. Technical parameters of the distribution network in Dili City

No	Substation	Feeder	End-of-Line Voltage	Voltage Drop	Loading	Percentage of Load	Losses
1	Camea	I	85,70%	14.30%	328,2 A	77,59%	8,11%
2		II	89,08%	10.92%	342,7 A	81,02%	4,17%
3		III	92,04%	7.96%	255,5 A	60,40%	3,05%
4		IV	95,74%	4.26%	361,7 A	85,51%	0,78%
5		V	91,91%	8.09%	355,5 A	84,04%	3,48%
6		VI	93,51%	6.49%	270,3 A	63,90%	3,36%

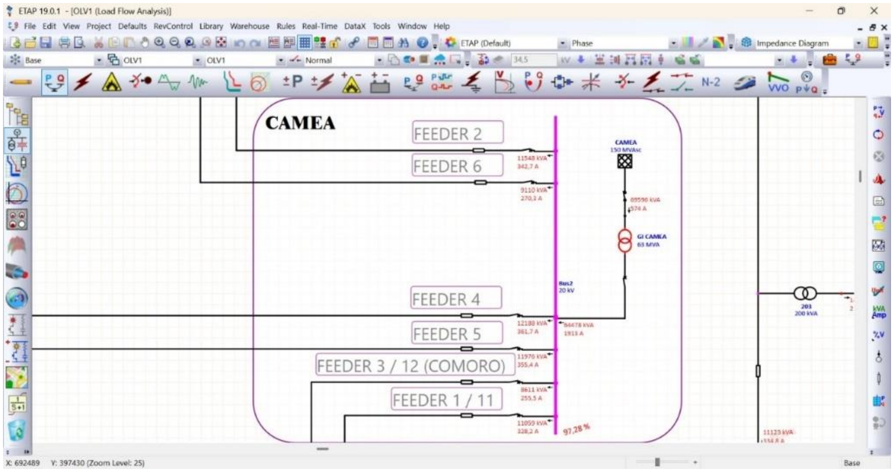

Figure 3. Camea substation loading under existing conditions

3.2 Impact of Substation Addition on Feeder Loading and Power Losses

Following the addition of the Comoro substation, there was a redistribution of load on the distribution network, whereby some of the load previously served by the Camea substation feeder was transferred to the feeder connected to the Comoro substation. This configuration change resulted in a decrease in the load level on the existing Camea substation feeder. In the new configuration, the feeder load on the west side of Dili City was transferred to the Comoro substation as the main supply, which was previously supplied by the Camea substation. Part of the load on feeder 1 of the Camea substation on the western side of Dili City was transferred and became feeder 1 at the Comoro substation. Meanwhile, all feeders 3 of the Camea substation were transferred and became feeder 2 at the Comoro substation.

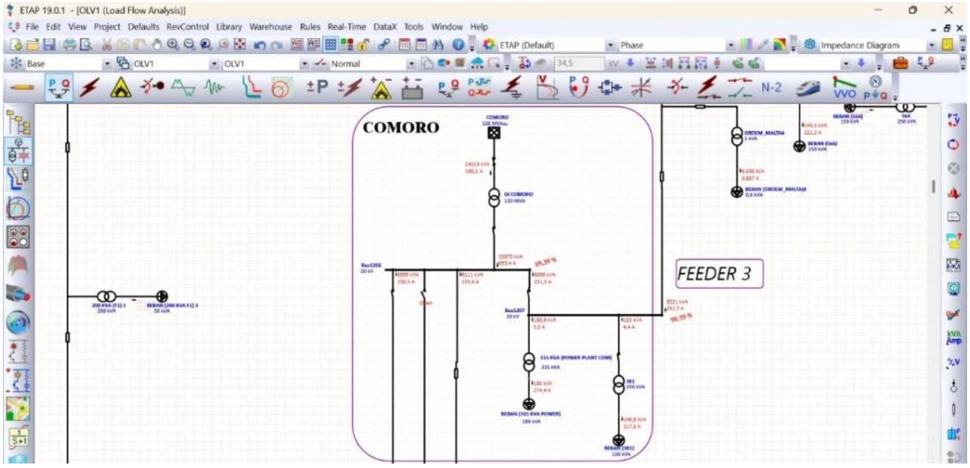

Figure 4. Feeder Loading of the Comoro Substation After Substation Addition

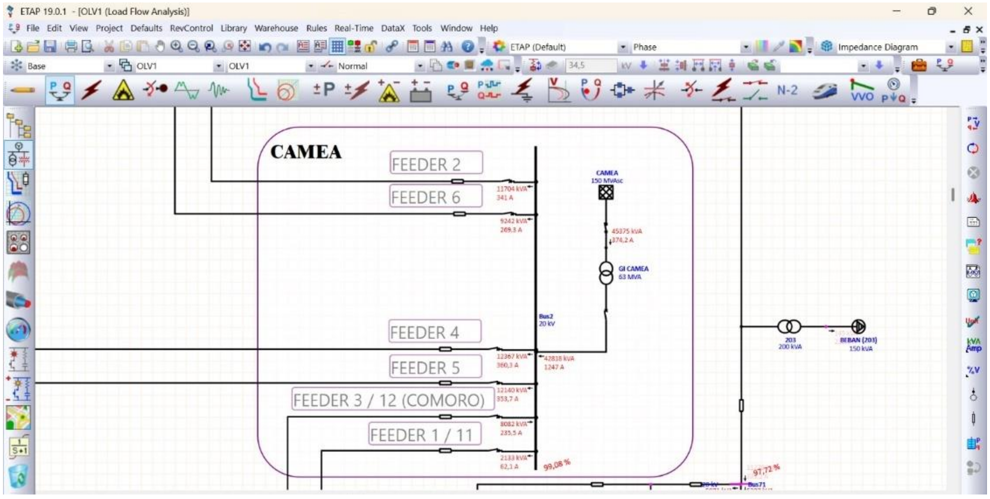

Figure 5. Feeder Loading of the Camea Substation After Substation Addition

The reconfiguration of the Dili City distribution network carried out on Feeder 1 and Feeder 3 of the Camea substation has reduced the load level at the Camea substation. The feeder load at the Camea Substation can be reduced and increase the capacity for load transfer or load addition due to future electricity supply demand. Meanwhile, the western side of Dili City has a new power supply that can provide electricity for future growth and increased demand for electricity supply. This shows that the addition of the Comoro Substation not only improves network performance but also provides long-term benefits to the reliability of the distribution system.

Table 4. Loading of Dili City Distribution Feeders After Substation Addition

No	Substation	Feeder	Current	Current Carrying Capacity	Percentage of Load
1	Camea	I	62,1 A	423 A	14.68%
2		II	341 A		80.61%
3		IV	360,3 A		85.18%
4		V	353,7 A		83.62%
5		VI	269,3 A		63.66%
6	Comoro	I	258,5 A	423 A	61.11%
7		II	251,5 A		59.46%

The reconfiguration of the 20kV distribution network in Dili City also had an impact on improving power losses in the network. Power losses in the distribution system are basically copper power losses that occur in conductors due to the flow of electric current through the resistance of the line. With the addition of the Comoro Substation, power distribution became more widespread and the length of the feeder lines became shorter, making network operating conditions more efficient. Technically, line power loss is proportional to the square of the current and conductor resistance. Therefore, the reconfiguration of the 20kV distribution network in Dili City, with the transfer of part of the existing feeder load to the Comoro Substation and the reduction in line length, has resulted in a decrease in total resistance, which ultimately has an impact on reducing the power loss value on each feeder.

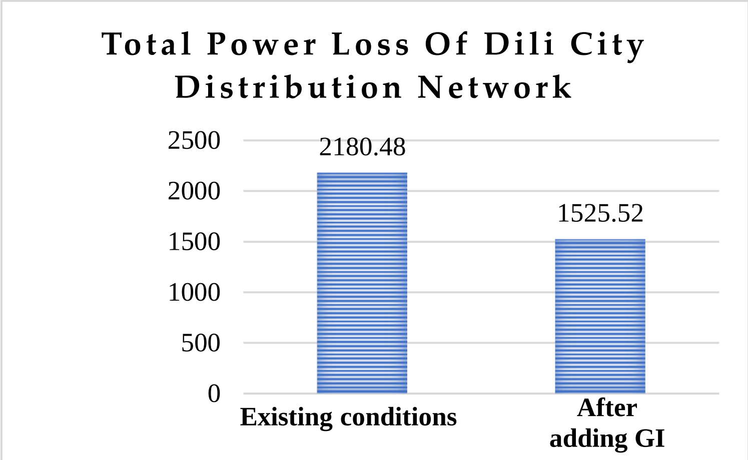

Figure 6. Camea substation loading under existing conditions

3.3 Impact of Substation Addition on Voltage Profile

The addition of a substation in Comoro to the 20 kV distribution network in Dili City has a direct impact on improving the system's voltage profile. Technically, the new substation serves as an additional power supply source closer to the load center, thereby shortening the distance between the power source and the load. This condition reduces the total impedance of the line through which the load current flows, which ultimately lowers the voltage drop in the distribution line.

Table 5. Voltage Drop of Dili City Distribution Feeders After Substation Addition

No	Substation	Feeder	End-of-Line Voltage	Voltage Drop	SPLN.72:1987 Standard	Remarks
1	Camea	I	98.67%	1.33%	10%	Compliant
2		II	90.93%	9.07%		Compliant
3		IV	97.56%	2.44%		Compliant
4		V	93.74%	6.26%		Compliant
5		VI	95.33%	4.67%		Compliant
6	Comoro	I	94.52%	5.48%	10%	Compliant
7		II	98.26%	1.74%		Compliant

Based on **Table 5.** shows that after the addition of the Comoro Substation, the voltage at the end of the feeder increased and became more evenly distributed throughout the network. This increase in voltage also brought the voltage profile in each feeder to the permitted standard value. Based on SPLN No. 72 of 1987, the voltage drop value in the network must not exceed 10% of the nominal voltage. The voltage drop at the end of each feeder is below 10%, with the highest voltage drop occurring at the end of feeder 2 of the Camea substation, reaching 9.07%. In addition, feeder 1, which experienced a voltage drop of up to 14.30% at the end of the line, experienced an improvement in voltage profile to 1.33% at the end of the line supplied by the Camea substation and 5.48% at the end of the line supplied by the Comoro substation. The configuration of the 20kV distribution network in Dili City after the addition of the Comoro substation allowed part of the load on Feeder 1 and the entire load on Feeder 3, which were previously supplied by long lines from the Camea substation, to be transferred to shorter feeders with voltage supply from the Comoro substation. With the reduction in feeder length, the total impedance value in the feeder conductors will automatically decrease, resulting in a smaller voltage drop along the feeder compared to the existing conditions.

4. Conclusion

The existing 20 kV distribution network in Dili City has technical problems related to voltage profile drops at the feeder ends and relatively high load values at each Camea substation feeder, reaching 14.30% on feeder 1. The structure of the 20 kV distribution network in Dili City has a radial system characteristic with relatively long feeder lengths and high feeder loading levels, causing the feeders to operate with high load currents, especially on feeders serving loads far from the Camea substation as the main supply source.

The new substation in the Comoro area can serve part of the load that was previously supplied by the Camea substation. The load on the west side of Dili City has been transferred to the Comoro substation as the main supply, including part of the load on feeder 1 and the entire load on feeder 3. This reduces the load on the Camea substation and increases its capacity to transfer loads or add loads due to future electricity supply demand.

The addition of a substation to the 20 kV distribution network in Dili City had a direct impact on improving the voltage profile of the network and the feeder load scheme at the Camea substation. There was an increase in the voltage profile across all feeders, thereby meeting the standards of SPLN No. 72 of 1987. The load level at the Camea substation has decreased to 72% of its capacity due to a reduction in feeder load, thereby increasing the capacity for load transfer or additional load from future electricity supply demand. The decrease in the load level also improved the power loss value in the network. With improvements in the voltage profile and power loss value, as well as increased load transfer capability in emergency conditions, the addition of the Comoro substation directly improved the performance of the 20kV distribution network in Dili City.

Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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