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Optimizing the Capacity of 150 kV Transmission Lines Through the Addition of Shunt Capacitors: Case Study at PT. PLN (Persero) West Sumatra Subsystem

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Abstract – *This study evaluates the impact of shunt capacitor installations on the voltage stability in the electrical network of the West Sumatra subsystem, focusing on the Pauh Limo, PIP, and Simpang Haru substations. The required shunt capacitor capacities to maintain a nominal voltage of 150 kV during peak loads were calculated as 155.57 MVAr for Pauh Limo, 82 MVAr for PIP, and 78.15 MVAr for Simpang Haru. However, PT PLN implemented a 50 MVAr in Pauh Limo substation. Despite this deviation from the calculated requirements, the installations effectively maintained the voltage within standard limits, with post-installation voltages at 144.3 kV, 144.9 kV, and 143.9 kV for the respective substations. This study demonstrates the necessity of balancing theoretical ideals with practical constraints in electrical engineering, highlighting that while optimal solutions are desired, real-world limitations often guide implementation strategies.*

Keywords*: Shunt capacitor, voltage regulation, nominal voltage, electrical transmission, electricity optimization*

I. Introduction

Reactive power, a fundamental aspect of electrical power systems, originates primarily from the impedance characteristics of transmission lines and is predominantly composed of reactive power components [1]. These characteristics are crucial because they significantly influence the efficiency and stability of power transmission. In addition, reactive power plays a vital role in the functioning of various electrical devices, including motors, transformers, and power electronic equipment. In these devices, reactive power is responsible for magnetizing and other phenomena that are essential for their operation; however, they do not contribute directly to the actual energy consumption [2]. This interplay between reactive power and electrical devices underscores their importance in both the transmission and consumption aspects of electrical energy, highlighting their critical role in the overall performance and efficiency of power systems [3].

In recent years, various innovative approaches have been developed to enhance the voltage and power qualities of electrical systems. [4] Presented an advanced method aimed at enhancing the sharing of reactive power among parallel-connected Distributed Generation (DG) systems within isolated microgrids. The proposed approach employs a compensator term featuring integral action to internally minimize reactive power-sharing discrepancies without necessitating inter-unit communication among DG units. [4] Work focused on a Particle Swarm Optimization (PSO) technique for reactive power and voltage control, incorporating a voltage security assessment. This approach addresses mixed-integer nonlinear optimization

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problems and formulates an online Volt/Var Control strategy by integrating various control variables, such as automatic voltage regulators and transformer tap positions.

Further advancements include [5] introduction of the Normalized Voltage Stability index and Load-Disabling Nodal Analysis. These tools help pinpoint the optimal placement and size of Reactive Distribution Generators (RDGs), enhance voltage stability, and reduce power loss. [6] Proposal of a hybrid compensator merges several components, such as thyristor switched capacitors and harmonic-tuned passive filters, to address power quality issues and facilitate the integration of renewable energy into unbalanced distribution systems. [7] suggested the use of a Modular Multilevel Converter combined with a supercapacitor-based energy storage system. This design focuses on active and reactive power compensation and is complemented by a cooperative control method for coordination with Static Var Compensators. [8] An Improved Unified Power Quality Conditioner optimizes the capacity by coordinating its series and parallel components, thereby enhancing the utilization rate of the series compensator. [9] Introduced a decentralized voltage control method for islanded microgrids, aiming to stabilize the voltage and prevent reactive power issues.

[10] Research has led to the development of a high-efficiency single-phase GaN-based rectifier designed for front-end power supplies and the utilization of a T-type totem-pole topology to address control challenges. [4] proposed a balanced design for dual-side LCC compensation, aiming for a unity power factor and aligning zero phase angle frequencies with those of the designed voltage gain across various conditions. [11] Optimized reactive power compensation strategy extends the operational range of cascaded H-bridge photovoltaic inverters, maximizing energy harvesting and minimizing reactive power. [12] introduced a primary detuned multifrequency compensation circuit to improve the misalignment tolerance of Inductive Power Transfer systems. [13] developed a novel dead-time compensation method that reduces harmonic distortion in the grid current, achieving high efficiency and low total harmonic distortion. These diverse studies reflect the ongoing efforts to improve power system performance and stability through advanced technological solutions.

Although insightful, this research is constrained by certain specific conditions [3][6][8][13], technologies [4][6][8][9][12], or scenarios that are not universally applicable [4][5]. The methodologies employed, such as specific models or simulations [4], do not entirely encapsulate the intricacies of real-world dynamics [7]. These methods often have inherent limitations that could affect the broader relevance of the study [4][5][13]. The system design and selection of parameters also involve inherent limitations or trade-offs that require careful consideration. For instance, choices made regarding the number of switching frequencies might involve a balance between the power loss, misalignment range, and power variation. Moreover, the way results are analyzed or interpreted could be limited by certain factors, including the metrics used or overlooked aspects [7][9].

In this research, the discussion will focus on the primary responsibility of the Dispatcher at UP2B Central Sumatera, which entails maintaining the system voltage quality within a range of +5% / -10% from the standard 150 kV voltage. With the evolving Electrical System of Sumatra, several Substations under UP2B Central Sumatera regulations are facing voltage-related issues. These challenges are attributed to various factors, such as the absence of supporting MVAr generation in nearby areas owing to maintenance [14], disruptions or expiration of rental power plant contracts [15], and a significant surge in consumer load demand [16].

To elevate the voltage to meet predefined standards, strategies including the enhancement of reactive power and transformer tapping have been employed [17]. When operating reactive power in power plants, it is critical to consider the capacity of the reactive power that the plant can generate because its impact directly influences the generator [18]. However, frequent usage of transformer tap changes at substations can affect the lifespan of transformers, rendering this method ineffective[12][19].

Another approach to voltage elevation involves the use of shunt capacitors [20]. In an electric power system, capacitors can be utilized to improve the power factor of transmission lines [21]. The installation of capacitors requires careful consideration because of their implications for aspects such as system control, cost, and voltage limits, necessitating precise calculations to determine the most suitable location and optimal capacity [22].

The installation of shunt capacitors at the Simpang Haru Substation was initially identified as a more effective and optimal solution. this study investigates the integration of shunt capacitors into the 150 kV transmission system at PT. PLN (Persero) in the West Sumatra Subsystem.

II. Theory

II.1. *Electrical Power Systems*

Electrical power systems are generally composed of three main components: power generation, transmission, and distribution [11][23]. Additionally, in several references, a fourth component, the substation, was included. The process begins at power generation centers, such as hydroelectric, thermal, gas turbine, combined cycle, and geothermal power plants, which are responsible for producing electricity [24]. The generated voltage is first increased using a step-up transformer before being transmitted through 70 kV or 150 kV transmission lines. After traversing the transmission lines, the electricity reaches the Substation, where its voltage is decreased using a step-down transformer to a medium voltage of 20 kV, known as primary distribution voltage [25].

From the Substation, this 20 kV electricity is distributed into a variety of distribution network configurations. In the primary distribution lines, part of the voltage is further reduced through step-down transformers located in distribution substations to a low voltage of 220/380 volts [25][26]. This low-voltage electricity is then distributed to end-consumers, such as residential and commercial buildings. For high- and medium-voltage consumers, the power supply is directly sourced from the incoming or outgoing lines of the Substation [25][27]. This comprehensive structure underlines the complexity and interconnectivity of the electrical power supply chain from generation to end-user distribution [28].

II.2. *Voltage Stability*

Voltage stability in power systems refers to the ability of a system to maintain voltages within specified limits at all buses under normal conditions and after disturbances [29]. Instability in voltage occurs when the system cannot control a drop in voltage, which is often triggered by an increased load or changes in conditions. The primary factor contributing to voltage instability is the inability of the power system to satisfy the reactive power demand. When unresolved, voltage instability can lead to a voltage collapse, a critical situation where the system fails to maintain voltage levels, leading to widespread power outages[30][31].

Factors contributing to the phenomenon of voltage collapse include limitations in the reactive power/voltage control of generators, load characteristics, reactive power compensator characteristics, and voltage control devices such as on-load tap-changing transformers [32]. To assess the extent to which the power system can supply power to the load, the power-voltage relationship curves were utilized. These curves are essential tools for understanding and predicting the behavior of power systems under various loading conditions, enabling engineers to evaluate the stability margin and take necessary actions to prevent voltage instability and collapse [19][26][33].

II.3. *Capacitor*

High-voltage capacitors are widely used in high-voltage installations and can be categorized based on their applications as power system capacitors, high-voltage laboratory capacitors, and high-frequency generation capacitors [34]. Capacitor banks play a crucial role in power-factor correction and voltage regulation in networks. They compensate for the reactive power and ensure that voltage levels are maintained under full-load conditions [35]. The installation of capacitor banks is a strategic measure to provide a reactive power supply, thereby reducing the reactive power absorption of the system by loads. This approach is critical for minimizing the voltage drops and network losses [36].

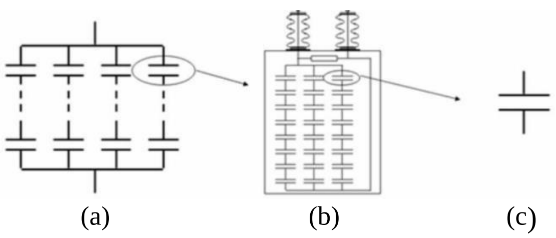

Fig. 1. (a) Capacitor bank, (b) Capacitor units, and (c) Capacitor Element

Several key components can be identified regarding the structural details of the capacitors.

a. Capacitor Bank: Capacitor units were assembled in galvanized steel racks to form a capacitor bank from single-phase capacitor units. The number of units in the bank depends on the required voltage and power. For higher power and voltage requirements, capacitor units are connected in both series and parallel configurations [37].
b. Capacitor Unit: A capacitor unit is an assembly of multiple capacitor elements connected in a series and parallel matrix. On average, a capacitor unit comprises about 40 such elements [38].
c. Capacitor Element: The smallest unit within a capacitor typically consists of a wound aluminum foil and a plastic film [39].

Capacitors perform several vital functions in power networks, such as improving the power factor, reducing network losses, neutralizing or eliminating voltage drops, and enhancing voltage stability [40]. These functions are integral to efficient and reliable operation of electrical power systems.

II.4. *Shunt Capacitor Bank*

In the context of power-factor correction and voltage regulation within electrical networks, the use of capacitor banks as part of a reactive power compensation system is crucial. Inductive loads in transmission lines absorb reactive power, often leading to voltage drops at the receiving end [39][41]. Capacitor banks compensate for this reactive power, ensuring that the voltage levels are maintained, especially under full-load conditions. The installation of capacitor banks is a strategic approach to provide a reactive power supply, thereby reducing reactive power absorption by the system loads. This reduction is essential for minimizing voltage drops and network losses.

The general functions of capacitors in power systems are diverse. They supply reactive power, maximize the utilization of complex power (KVA), improve the power factor, reduce voltage drops, prevent transformer overloading, add available power, avoid increases in current and temperature in cables, and enhance the efficiency [42]. Moreover, voltage regulation using capacitor banks not only improves the voltage values but also enhances the power factor. This is because the installation of capacitor banks reduces the absorption of reactive power by the loads, thereby improving the power factor. The operational process of capacitors involves their installation parallel to the load circuit. When a voltage is applied, the electrons flow into the capacitor. As the capacitor discharges, it generates reactive power required by the circuit. When the voltage stabilizes, the capacitor stores electrons again.

The shunt capacitor installation is vital for efficient power systems. It is evident that transmission lines are the most effective when transmitting only active power, with the reactive power needs of the load being met within the distribution system. This enables the optimization of transmission lines, improved operational performance, and reduced losses. Shunt capacitors also serve as an additional reactive power source to compensate for the reactive power in the electrical network, thereby maintaining the voltage profile within permissible limits. They are connected parallel to the network or load, aiming for power-factor correction, voltage regulation, and reduction in power and voltage losses in the network [43].

III. Research Method

III.1. *Voltage Drop Calculation*

Calculating the voltage drop in transmission lines is a pivotal process in electrical engineering to ensure an efficient and reliable distribution of power. In transmission systems, the voltage drop is influenced by factors such as line impedance, transmission distance, and load current. Impedance, which comprises both resistance and reactance, plays a significant role in this context. As electric power is transmitted over long distances, the resistance and inductance of the transmission lines cause a gradual decrease in voltage. This phenomenon becomes increasingly pronounced at longer transmission distances and higher load currents. Engineers employ specific equations based on principles such as Ohm's law to accurately predict the voltage drop across transmission lines. These calculations are integral for designing systems that can effectively deliver power within acceptable voltage limits to end users, thereby maintaining the stability and efficiency of the power system. Proper management and mitigation of voltage drops are essential for minimizing energy losses, maintaining power quality, and ensuring the longevity of electrical infrastructure.

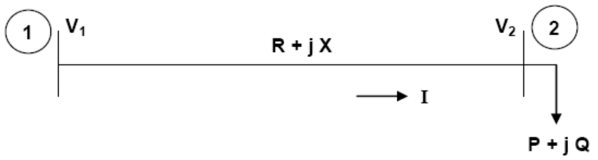

Fig. 2. The transmission line (voltage bus) supplied the load bus.

In Fig. 2 bus 1 is the voltage bus (V_1) and bus 2 is the load bus (V_2), the impedance is $(R + jX)\Omega$, R is the resistance in the transmission line and X is impedance.

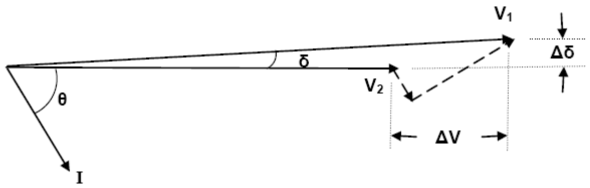

Fig. 3. Phasor diagram

Taking (V_2) as a reference, the current that appears has a different phase angle of θ with respect to (V_1). Meanwhile, the $(R + jX)$ value is the transmission line impedance value, and the $(P + jQ)$value is the load impedance value, from which the (ΔV) and $\Delta\delta$ values are obtained, so that a phasor diagram such as that in Fig. 3 can be written as Equation 1.

$$V_1^2 = (V_2 + \Delta V)^2 + \Delta\delta^2 \quad (1)$$

Where, $\Delta V = \frac{R_P}{V_2} + \frac{X_Q}{V_2}$ and $\Delta\delta = \frac{R_Q}{V_2} + \frac{X_P}{V_2}$

Usually, $\Delta\delta << (V_2 + \Delta V)$, so Equation 1 can be simplified to: $V_1^2 = (V_2 + \Delta V)^2$ or $V_1 = (V_2 + \Delta V)$. Therefore, the voltage drop in the transmission line is given by Equation 2.

$$V_1 - V_2 = \Delta V = \frac{R_P}{V_2} + \frac{X_Q}{V_2} \quad (2)$$

Because $R << X$, the value of R can be ignored, so

Obtained in Equation 3.

$$\Delta V = \frac{X_Q}{V_2} \quad (3)$$

were, V_1 is voltage on the source side, V_2 is voltage on the load side, P is active power, Q is reactive power, ΔV is difference V_1 and V_2 , θ is angle between I and V_1, δ is angle between V_2 and V_1, or $\Delta\delta = \theta - \delta$. I is load current, R is transmission line resistance and X is transmission line reactance.

An analysis of Equations 1 through 3 reveals a direct proportionality between the voltage drop across the transmission lines and the reactive power flowing through these lines. Electrical loads typically exhibit inductive characteristics. During peak load periods within a day, there is an escalation in the reactive power flow, which in turn amplifies the voltage drop. In contrast, periods of low demand show an increase in line capacitance, leading to a unique situation in which the voltage at the receiving end surpasses that at the sending end, which is known as the Ferranti Effect. Thus, the management of reactive power is pivotal for maintaining the voltage drop in transmission lines within designated limits. One effective strategy during high-demand periods is the parallel installation of capacitors in the system, which reduces voltage drop. To calculate the resultant voltage increase when shunt capacitors are deployed, Equation 3 can be utilized, where Q denotes the capacity of the installed capacitors. The capacitor bank installed at the substation in the Pauh Limo, Simpang Haru, and PIP substations is shown in Fig. 4.

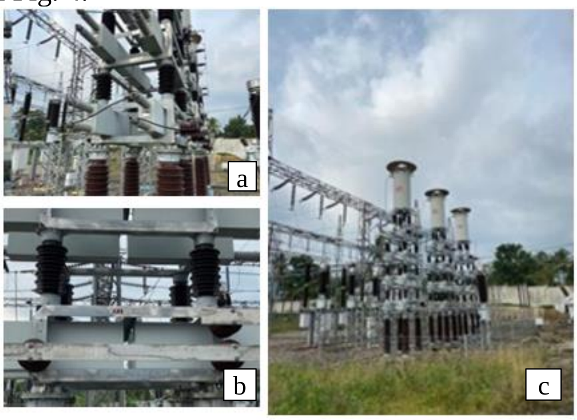

Fig. 4. (a,c) Capacitor bank installed at the substation Pauh Limo (c) name plate

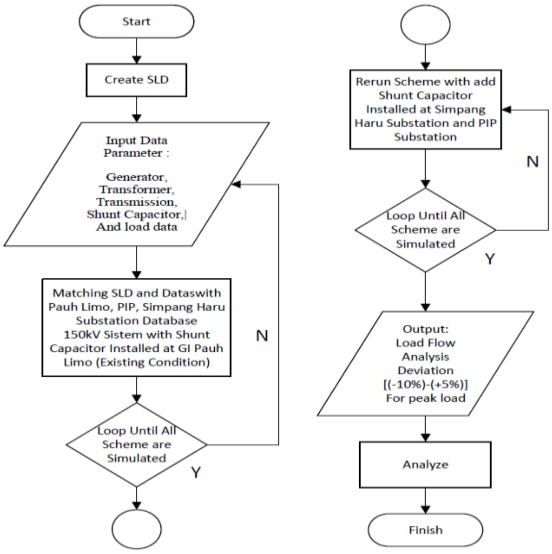

Fig. 5. Flowchart Diagram

Load-flow analysis in Digsilent PowerFactory:
Using the specifications and the parameters obtained from Pauh Limo, PIP, and Simpang Haru substation. The network transmission was modelled in Digsilent PowerFactory. The system is simulated under various load conditions. The loop continues until all relevant schemes have been simulated. Add Shunt capacitor to Simpang Haru and PIP substations with the same specification as Pauh Limo. The system simulated again with the new configuration. Load flow analysis is performed to evaluate the systems performance. Key metrics such as voltage deviation are calculated. The result of the simulations is analyzed to determine the optimal shunt capacitor placement. The deviation from the target voltage range (-10% to +5%) is assessed for peak load conditions. Based on the analysis simulation a decision is made regarding the placement of the shunt capacitor.

III.2. *Tools*

In this study, DIgSILENT PowerFactory software was utilized. The DIgSILENT PowerFactory is a sophisticated and integrated engineering software designed for industrial, utility, and electric power system analyses. It stands out as an interactive software package dedicated to power systems and control analysis, with the primary objective of facilitating planning and optimizing operations. The DIgSILENT PowerFactory 15, a specific version of this software, is particularly capable of conducting power flow studies on large-scale systems with an unlimited number of buses. This makes it an ideal tool for analyzing extensive systems, such as the 150kV and 275kV systems of PT.PLN (Persero) in Central Sumatra, which are characterized by their large scale and numerous buses. The adaptability and comprehensive analysis capabilities of the DIgSILENT PowerFactory 15 render it a valuable resource for power system analyses in complex networks.

IV. **Result and Discussion**

The voltage drop in transmission networks refers to the difference between the sending-end voltage and receiving-end voltage. This occurrence is influenced by several factors, including line impedance, phase angle difference between the current and voltage, load magnitude, and distance.

In the context of the Pauh Limo Substation, there was a noted decrease in voltage from February to March, from 151 kV to 146 kV. Similarly, the Simpang Haru Substation experienced a drop from 151 kV to 147 kV, and the PIP Substation saw a reduction from 153 kV to 148 kV, shown in Fig. 5. Such voltage reductions can occur when the generation capacity is compromised because of maintenance or operational disruptions. The amount of MVAr generated by the plants depends on the voltage conditions, and the voltage regulation can be managed through operational adjustments during generation or by employing capacitor banks. As the electrical system in Sumatra evolves, substations around the city of Padang face voltage challenges owing to factors such as lack of supportive MVAr generation in the vicinity owing to maintenance, expired contracts, or rental power plants, despite significant load growth. Building new-generation plants is not a viable short-term solution because of the length of the process; therefore, the installation or relocation of capacitor banks is an effective strategy for maintaining voltage within normal limits.

The potential causes of voltage drops in the West Sumatra subsystem include seasonal changes from the rainy to the dry season. During the dry season, hydroelectric power plants (PLTA) require operational strategies to maintain normal voltage levels, whereas thermal power plants (PLTU) face reduced coal supply, impacting their operational efficiency. In addition, disruptions and maintenance in the thermal generation facilities in the West Sumatra subsystem, specifically the PLTU Ombilin and PLTU Teluk Sirih, along with the maintenance of several plants and increasing customer loads in central Sumatra, contribute to these voltage challenges.

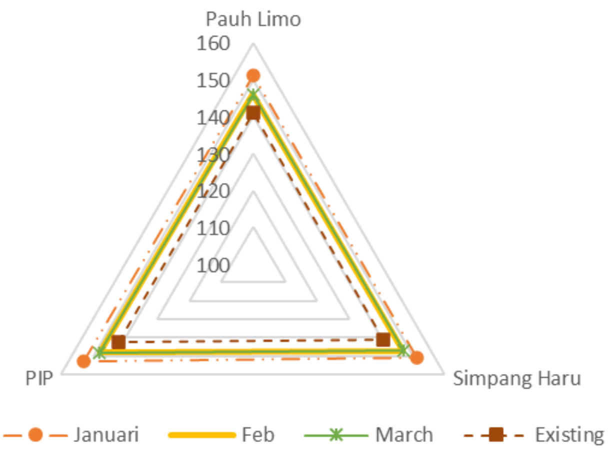

Fig. 6. Voltage graph at the substation

Table 1. Generation in the West Sumatra Subsystem from January to March 2023

No	Power Plants	Operate					
		Jan.		Feb.		March	
		MW	MVAr	MW	MVAr	MW	MVAr
1	PLTU Ombilin #1	80,8	3	0	0	80,9	11
2	PLTU Ombilin #2	0	0	80,4	43	61,2	14
3	PLTG Pauh Limo	0	0	0	0	0	0
4	PLTU Teluk Sirih #1	90	-3	72	24	91	6
5	PLTU Teluk Sirih #2	88	-3	0	0	88	12
6	PLTG Teluk Sirih	0	0	0	0	0	0
7	PLTA Maninjau #1	16,1	1,3	16,1	1,3	16	0,9
8	PLTA Maninjau #2	16,1	1,5	16,1	1,3	16,3	0,8
9	PLTA Maninjau #3	15,9	1,7	16	1,2	15,7	0,5
10	PLTA Maninjau #4	16,2	1,2	16,1	1,4	0	0
11	PLTA Batang Agam #1	3,2	0	3,3	0	3,3	0
12	PLTA Batang Agam #2	3,4	0	3,4	-0,2	3,4	0
13	PLTA Batang Agam #3	3,5	0	3,5	-0,1	3,5	0
14	PLTA Singkarak #1	35,9	0,9	42,1	-1,4	35,5	-0,9
15	PLTA Singkarak #2	35,9	1,2	41,9	5,3	36,5	-1
16	PLTA Singkarak #3	35,6	1,4	42,7	9,8	36,9	-1,9
17	PLTA Singkarak #4	35,3	0,1	41,7	3,5	36,3	1

The existing voltage conditions at the Pauh Limo Substation witnessed a decline from its standard level of 146 kV to 141.1 kV. Similarly, the voltage at the Simpang Haru Substation decreased from its normal 147 kV to 140.7 kV, and the PIP Substation saw a drop from the usual 148 kV to 142.1 kV, Shown in Fig. 5.

During this period, the operational power generation included PLTU Ombilin unit 2, producing 60.5 MW with a reactive power of 24 MVAr. PLTA Maninjau unit 1 was generating 10 MW with a reactive power of 2 MVAr. PLTA Batang Agam was operating three units, with unit #1 generating 2.4 MW, unit #2 at 2.5 MW, and unit #3 at 2.6 MW. Additionally, PLTA Singkarak unit #3 was producing 30 MW with a reactive power of 21.9 MVAr, Shown in Table. 2.

The installation of capacitors at the Pauh Limo Substation resulted in a voltage increase from 141.1 kV to 144.3 kV (Fig.6.). At the Simpang Haru Substation, the voltage rose from 140.7 kV to 143.9 kV (Fig.7), and at the PIP Substation, it increased from 142.1 kV to 144.9 kV (Fig.8). The capacity of the shunt capacitors was calculated during peak load at 19:00 WIB on March 26, 2023. At that time, the voltage at the Pauh Limo Substation was 141.1 kV (V1), and the network impedance from the Pauh Limo Substation to the Indarung Substation was 8.57 Ohms. Using Equation 3, the voltage improvement from the Pauh Limo Substation to the GIS Simpang Haru can be calculated and analyzed.

Table 2. generation during Existing Conditions in the West Sumatra Subsystem

No	Power Plants	Operate	
		MW	MVAr
1	PLTU OMBILIN #1		
2	PLTU OMBILIN #2	60,5	24
3	PLTG PAUH LIMO		
4	PLTU TELUK SIRIH #1		
5	PLTU TELUK SIRIH #2		
6	PLTG TELUK SIRIH		
7	PLTA MANINJAU #01	10	2
8	PLTA MANINJAU #02		
9	PLTA MANINJAU #03		
10	PLTA MANINJAU #04		
11	PLTA BATANG AGAM #01	2,4	
12	PLTA BATANG AGAM #02	2,5	
13	PLTA BATANG AGAM #03	2,6	
14	PLTA SINGKARAK #01		
15	PLTA SINGKARAK #02		
16	PLTA SINGKARAK #03	30	21,9
17	PLTA SINGKARAK #04		

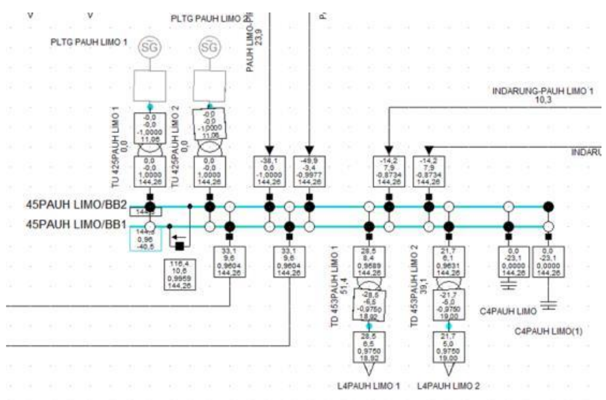

Fig. 7. Simulation of Capacitor Installation at Pauh Limo Substation

Utilizing Equation 2 to achieve a desired receiving-end voltage of 150 kV at the Pauh Limo Substation (GI Pauh Limo), it was determined that a reactive power of 155.57 MVAr needs to be injected into the network, representing the required shunt capacitor capacity. However, this calculated value shows a significant variance from the shunt capacitor capacity already established by PT.PLN (Persero), which is 25 MVAr. Given that one capacitor with a capacity of 25 MVAr is already installed at the GI Pauh Limo, the total installed capacitor capacity at this substation amounts to 2 x 25 MVAr. This discrepancy between the calculated reactive power requirement and the existing capacitor capacity highlights the need for reassessment or adjustment of the reactive power management strategy to achieve the targeted voltage level at the substation.

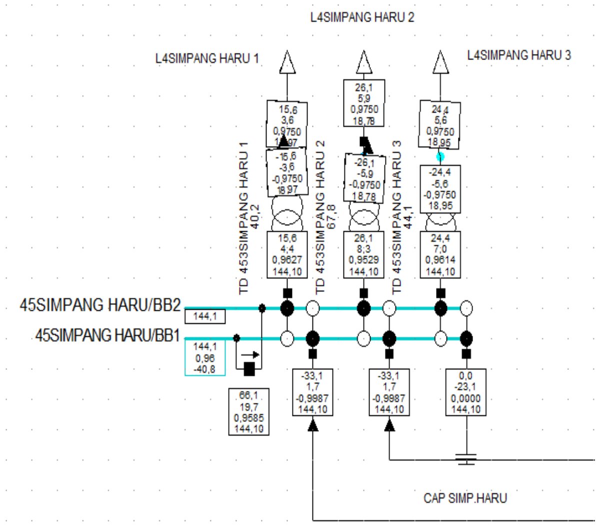

Fig. 8. Simulation of Capacitor Installation at Simpang Haru Substation

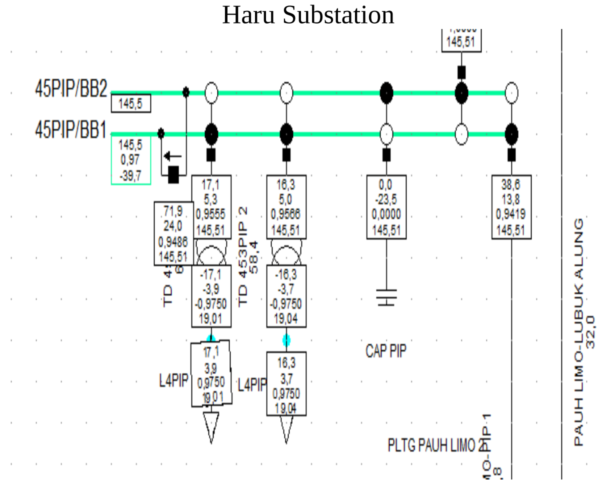

Fig. 9. Simulation of Capacitor Installation at PIP Substation

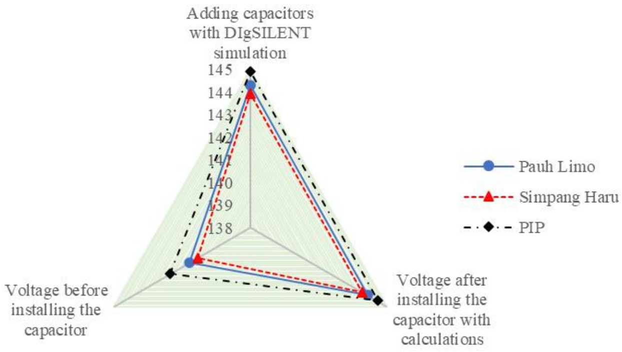

Fig. 10. Comparison of voltage before and after installing the capacitor with calculations and with DIgSILENT simulation

When calculated with a reactive power (Q) value of 50 MVAr, the voltage at the Pauh Limo Substation (GI Pauh Limo) is determined to be 144 kV. By injecting 50 MVAr of reactive power into the network, the busbar voltage at the receiving end, specifically at the GI Pauh Limo, stands at 144.0 kV, Shown in Fig. 9. This voltage level still complies with the standard voltage drop for a 150 kV system as per the Regulation of the Minister of Energy and Mineral Resources No:03 of 2007, which allows a deviation of +5% and -10%. Therefore, PT. PLN's initial study involving the use of a 25 MVAr shunt capacitor does not result in adverse effects, even though the voltage at the GI Pauh Limo does not reach its nominal value during peak load conditions. Due to the unavailability of 25 MVAr capacitors in the market, this capacity can be achieved by connecting several capacitor units in series and parallel across each phase, thereby fulfilling the total requirement of 25 MVAr. This approach ensures that the desired reactive power compensation is met while adhering to the regulatory standards and maintaining the stability of the power system.

V. Conclusion

Installation Capacitor bank in Pauh Limo Substation was significantly aids in maintaining the voltage levels at the Pauh Limo Substation and several nearby substations. The calculated capacity of shunt capacitors needed to achieve the nominal voltage of 150 kV during peak load is 155.57 MVAr for the Pauh Limo Substation, 82 MVAr for the PIP Substation, and 78.15 MVAr for the Simpang Haru Substation. However, following PT PLN's decision to install capacitors with a capacity of 25 MVAr, the voltage levels still meet the requirements: 144.3 kV at the Pauh Limo Substation, 144.9 kV at the PIP

Substation, and 143.9 kV at the Simpang Haru Substation. These values indicate an improvement in the voltage quality of the Sumbar sub-system and are in accordance with the standard voltage regulations.

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