Comparative Analysis of Static Var Compensator and Distributed Generation Installation on Voltage Profile

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Abstract— In Indonesia, electricity is a basic need with demand that continues to grow. PT PLN (Persero) projects an increase in electricity consumption of 8.9% by early 2022, highlighting the urgent need to address frequent problems such as blackouts, power losses, and voltage sags in the power distribution system. Effective solutions, including Static VAR Compensator (SVC) and Distributed Generation (DG), have been proposed to improve voltage stability and reduce power losses. This study evaluates and compares the performance of SVC and DG on a standard IEEE 14-bus system under increased load conditions. Using power flow analysis in ETAP, we simulate the installation of SVC at 15.99 Mvar and DG at 20.58 Mvar on bus 9, which shows optimal results. The findings show that DG slightly outperforms SVC in improving voltage stability and reducing power losses, with a 0.16% greater voltage increase and a 3.2 MW or 17.3% reduction in power losses. These results indicate that although both devices meet PLN's voltage standards and improve power system efficiency, DG provides a slightly superior improvement in overall system performance.

Keywords: SVC; DG; Voltage; Electrical System; and Voltage Drop

I. Introduction

In this century, electricity is a vital necessity in Indonesia. PLN Indonesia predicts that electricity demand will increase by 8.9% at the beginning of 2022, following a previous decline of -0.79% due to the pandemic [1]. In 2022, PT PLN reported that the total electricity sold reached 273,761.48 GWh. Of this amount, the industrial sector consumed 88,483.30 GWh (32.32%), the residential sector consumed 116,095.41 GWh (42.41%), businesses consumed 50,532.19 GWh (18.46%), and other sectors, including social services, government buildings, and public street lighting, accounted for 18,650.58 GWh (6.81%).

Power losses and voltage drops are common issues in electrical power systems. Factors contributing to power losses include climate, distance, and corona effects [2]. Power losses occur in every system, and to minimize these losses, maintaining a good voltage profile is required. According to PLN standards (SPLN Number 1, 1978), a good voltage profile for low-voltage networks is defined as being within 5% above or 10% below the nominal voltage of 220V, which translates to a maximum of 230V and a minimum of 198V.

Climate change can negatively impact electrical systems. Increased temperatures from hot climates can increase the frequency of AC use, which in turn affects electrical loading [3]. In hot climates, heat exposure can increase by 2.33% per degree Celsius [4]. This increased load affects voltage profiles and power losses and must be accounted for in power systems. BMKG studies from 1980 to 2010 indicate that normal temperatures in Indonesia typically range from 21.3 to 29.7 degrees Celsius [5]. Temperatures above this range may lead to a rise in electrical load, further impacting system stability.

Many solutions can address power loss and voltage drop issues, one of which is the use of capacitor banks [6]. Other solutions include distributed generation, Flexible AC Transmission Systems (FACTS) devices, cable resetting, power charging, and network reconstruction. Given the various methods available to address voltage profile issues, a comparative study of these tools is necessary.

The Static VAR Compensator (SVC) is one of the FACTS devices designed to reduce power losses and improve voltage stability. SVC operates by absorbing and generating reactive power through the control of the thyristor angle [7].

In addition to FACTS devices, another tool that can improve voltage profiles and reduce power losses is distributed generation (DG). Distributed generation refers to generators that produce electricity with a smaller capacity than conventional power plants and can be installed in almost any electrical network [8]. Installing DG in the power system can provide positive effects, including increased system supply reliability, reduced power losses, and improved power quality and profile. The author chooses DG for its advantages and its applicability to various regions requiring electricity [8]. Furthermore, the author aims to evaluate the effectiveness of SVC in enhancing voltage profiles and reducing power dissipation compared to non-FACTS devices.

To conduct voltage profile and power loss studies, a power flow study must be performed. A power flow study provides information about the network's state, including

Received 24 July 2024, Revised 26 October 2024, Accepted 16 Januari 2025.
DOI: https://doi.org/10.15294/jte.v16i1.8824

voltage differences at each bus, active and reactive power in the network, and other network data [6].

Research related to SVC and DG has been conducted by previous researchers. One study on SVC discusses the effects before and after SVC installation. It was found that SVC installation reduced active power losses from 68.5 MW to 43.7 MW, and reactive power decreased from 256.4 MVAR to 160.8 MVAR [9]. Next research related to SVC, one notable study focuses on improving voltage stability at bus GI Alas 2 in the Sumbawa power system using an SVC. The method used includes a block diagram model of the SVC provided by DigSilent Power Factory, with P-V curve and dynamic analysis. The results show that the installation of a 4 Mvar SVC increases the voltage profile from 0.81 p.u to 0.98 p.u and the voltage stability margin from 7.22 MW to 17.83 MW. Nearby buses, GH Alas and GH Utan, also experience increased loading [10]. The third related SVC study examines voltage losses on the 150 kV transmission line in Cibatu and Mandirancan sub-systems, PLN APB West Java, using ETAP software version 12.6. SVC installation at Dawuan substation improved voltage losses by 13.56%. Initially, SCADA recorded 224.71 kV losses; ETAP showed 220.604 kV. Post-SVC, ETAP indicated improvements of 9.098 kV to 29.903 kV for SVC ratings of 50 to 199 MVAR. Optimal placement is at Dawuan Substation [11]. The fourth study examines the impact of SVC installation on voltage stability in Batam's industrial electrical system. Using the Newton-Raphson method within ETAP, the study simulates the power system before and after adding the SVC. Results show that the SVC installation significantly increased voltage at bus 20 kV GI Tj. Uban from 18.157 kV to 19.289 kV, an improvement of 1.132 kV. While the SVC did not alter the direction of power flow, it reduced losses at the Tj. Uban substation from 30.7 kW and 1380 kVAR to 5.6 kW and 253.7 kVAR [12]. The fifth study tackles power quality issues from non-linear loads like electric arc furnaces (EAF). A hybrid system using a matrix converter (MC) and SVC was simulated in MATLAB. Results showed improved power quality THD of current and voltage reduced to 2.85% and 29.54%, voltage flicker to 1.26%, and power factor to 0.9975. This model, tested in a steel plant, demonstrated superior performance in reducing arc current and voltage peaks, enhancing overall power quality [13].

Then, the first study related to DG concluded that DG could improve voltage profiles and address power loss issues in the studied feeder [14]. The second study addresses power loss and voltage instability in distribution systems by optimizing the placement of distributed generation (DG) units. Using particle swarm optimization on the IEEE-33 bus system, power loss was reduced by 68.05%, and voltage improved by 6.53% after reconfiguration. Results showed a decrease in power loss from 203.17 kW to 138.14 kW, and voltage increased from 0.9022 p.u. to 0.9611 p.u. with DGs, enhancing system stability and efficiency [15]. The third study models a 69-bus radial distribution system, optimizing DG placement using MLSA in MATLAB. The goal is to reduce power losses and improve the voltage profile. Results show power losses reduced from 148.236 kW to 56.026 kW, demonstrating the effectiveness of the approach [16]. The fourth study integrates solar DG (PLTS-DG) to improve voltage profile and reduce power losses on the 20 kV Lombok, NTB system using ETAP software. Newton Raphson method for power flow analysis showed that installing PLTS-DG at bus 90 on Sheraton feeder improved the voltage profile to 0.9552 p.u. and reduced power losses from 3.278 MW and 19.364 MVar to 3.245 MW and 19.292 MVar [17].

Then, combined study examines SVC and DG, first study addresses power loss reduction, voltage profile enhancement, and operational cost minimization in power systems using SVC and DG. The study employs an objective function constrained by equality and inequality conditions to diagnose dynamic issues in various environmental conditions. It uses the Loss Sensitivity Factor (LSF) to identify initial locations for DG and Distribution static compensators, while Dwarf Mongoose Optimization (DMO) determines their optimal size and final placement. The integrated approach effectively minimizes power loss, improves voltage profiles, and reduces operational costs. The system's performance is tested in MATLAB/Simulink using IEEE benchmark systems, showing significant improvements in dynamic stability [18].

The second study investigates the impact of distributed generation on network losses and operational costs in distribution systems. With DG frequently connected to the distribution network, it significantly affects network losses. The study examines the cost of annual energy losses and potential savings from optimally placing DG and Static Var Compensators (SVCs). The strategic deployment of DG sources and FACTS devices is shown to reduce technical losses and operational costs in distribution networks, emphasizing the importance of optimal placement and sizing [19]. From these studies, we know that both tools can minimize performance losses. However, it remains to be determined which of these two tools is the most effective to install.

As a case study, the IEEE 14-bus system is used in this research. The IEEE 14-bus system is a published system representing the standard electrical system of 1962. This system has 14 buses, 5 generators, and 11 loads [20]. The author chose the IEEE 14-bus case study to ensure a more accurate comparison, as IEEE 14 is a standard case study, eliminating potential bias in the system used. This study will compare voltage profiles and power losses before and after the installation of SVC and DG and determine which device is optimal for minimizing power losses and improving voltage profiles. The study will also be simulated with a load of 104.66% to represent a hot climate, where climate can be a factor affecting voltage drop and power losses.

This research addresses the important issues of rising electricity demand and the associated challenges of power losses and voltage drops in Indonesia's electrical system. As electricity consumption increases, maintaining voltage profiles becomes essential to mitigate losses caused by factors like climate, distance, and corona effects. The evaluation focuses on the effectiveness of Static VAR Compensators (SVC) and Distributed Generation (DG) in enhancing voltage stability and reducing power losses, providing insights into potential solutions for improving the reliability of Indonesia's electrical network.

II. METHOD

A. Research Parameters

Before entering the calculation process, it is necessary to obtain the parameters for the single-line diagram, which explains the components of the installation and how they are connected. This is important for the ETAP simulation, as having an accurate single-line diagram is essential. Below are the parameters for the IEEE 14-bus system.

TABLE I. IEEE 14-BUS SCHEMATIC [21]

Parameter	Value
Number of Buses	14.00
Number of Line-to-Line Connections	20.00
Number of Generators	5.00
Number of Power Grids	0.00
Number of Loads	12.00
Number of Transformers	4.00

TABLE II. TRANSFORMERS PARAMETERS [21]

From Bus	To Bus	Power Rating (MVA)	Freq. Rating (Hz)	R (pu)	X (pu)	Tap Ratio
5	6	100	60	0	0.25	0.93
4	7	100	60	0	0.20	0.98
4	9	100	60	0	0.57	0.97
8	7	100	60	0	0.18	0.00

TABLE III. GENERATOR PARAMETERS [21]

Location	Power (MW)	Power (MVAR)
BUS 1	232.40	-16.90
BUS 2	40.00	42.40
BUS 3	0.00	23.40
BUS 6	0.00	12.20
BUS 8	0.00	17.40

TABLE IV. LOAD PARAMETERS [21]

Name	BUS	PF (%)	Active Power (MW)	Reactive Power (MVAR)	AMP
Load 2	BUS 2	86.31	21.70	12.70	14516
Load 3	BUS 3	98.03	94.20	19.00	55482
Load 4	BUS 4	-99.67	47.80	-3.90	27689
Load 5	BUS 5	97.86	7.60	1.60	4484
Load 6	BUS 6	83.09	11.20	7.50	7782
Load 9	BUS 9	87.15	29.50	16.60	19543
Load 10	BUS 10	84.06	9.00	5.80	6182
Load 11	BUS 11	88.93	3.50	1.80	2272
Load 12	BUS 12	96.73	6.10	1.60	3641
Load 13	BUS 13	91.88	13.50	5.80	8483
Load 14	BUS 14	94.80	14.90	5.00	9074

TABLE V. LINE PARAMATERS [21]

BUS	R (pu)	X (pu)	Y (pu)
1-2	0.02	0.10	0.05
1-5	0.05	0.22	0.05
2-3	0.05	0.19	0.04
2-4	0.06	0.17	0.04
2-5	0.06	0.17	0.03
3-4	0.07	0.17	0.03
4-5	0.01	0.04	0.01
6-11	0.09	0.20	0.00
6-12	0.12	0.25	0.00
6-13	0.07	0.13	0.00
7-8	0.00	0.18	0.00
7-9	0.00	0.11	0.00
9-10	0.03	0.08	0.00
9-14	0.13	0.27	0.00
10-11	0.08	0.19	0.00
12-13	0.22	0.20	0.00
13-14	0.17	0.35	0.00

B. SVC Rating Calculation Method

The calculation method is performed to ensure that the load side voltage equals the source side voltage. or VR ≈ VS [22]. If the active power at the load end approaches 1 (pf = 1) and VR ≈ VS. the value of δ is obtained using the following formula:

$$P_R = \frac{|V_R|=|V_g|}{|B|}\text{Cos}\ (\beta-\delta) - \frac{|A|}{|B|}|V_R|^2\text{Cos}\ (\beta-\alpha) \quad (1)$$

where P_R represents the active power at the receiving end. with $|V_R|.|V_g|$ denoting the magnitudes of the receiving end voltage and sending end voltage. respectively. The terms |A| and |B| are network parameters. while β. δ. and α are phase angles related to the voltages and network parameters. Then. the formula for QR is:

$$Q_\pi = \frac{|V_d|=|V_\pi|}{|B|}\text{Sin}\ (\beta-\delta) - \frac{|A|}{|B|}|V_n|^2\text{Sin}\ (\beta-\alpha) \quad (2)$$

where Q_π denotes the reactive power on the receiving end. The symbols $|V_d|.|V_\pi|$ refer to the magnitudes of voltages associated with the load. while |Vn| represents the network voltage magnitude. The terms |A| and |B| are again network parameters. and β. δ. and α are phase angles. as noted earlier. Then. kVAR before SVC is:

$$Q_1 = P\ \text{Tan}\ \theta_1 \quad (3)$$

where Q_1 is the reactive power before adding an SVC with P indicating active power and θ_1 the power angle before compensation. Based on the power factor. Q can be found using the following equation; desired kVAR based on PF = 0.999:

$$Q_2 = P\ \text{Tan}\ \theta_2 \quad (4)$$

where Q_2 which is the target reactive power needed to achieve the desired power factor. such as PF = 0.999. Then. θ_2 represents the power angle required to reach this target power factor. Using equation 4. Q can be refined with the following equation:

$$Q = Q_2 - Q_1 \quad (5)$$

C. DG Calculation

DG is classified according to its power: micro (<5kW). small (5kW-5MW). medium (5MW-50MW). and large (50MW-500MW). To determine the DG capacity. the rule of thumb calculation method is used [23] [24]:

$$Capacity = \frac{2}{3}.total\ load\ on\ the\ bus \quad (6)$$

D. Placement of SVC and DG

The location for placing DG and SVC will be on the identified weak buses. The author will place SVC and DG one by one on the identified weakest bus and determine the optimal result from these individual trials. After testing. bus 9 was found to be the most optimal location.

III. RESULTS AND DISCUSSION

A. Existing Power Flow of IEEE 14-Bus

In the initial stage. to determine the voltage at each bus. an existing power flow analysis is conducted using ETAP 19.0.1. The power flow in this study utilizes the Fast Decoupled Method. and the results are shown in Table VI.

B. Rating of Static Var Compensator

From the simulation results. it is found that 10 buses are at critical limits. 1 bus is at a marginal limit. and 1 bus is outside the SPLN standard. Bus 9 is identified as having a significant voltage drop. thus SVC will be installed at bus 9. The SVC rating to be applied is according to equations (1) to (5).

C. Rating of Distributed Generation

From the power flow simulation results. 10 buses are within critical limits. 1 bus is within marginal limits. and 1 bus is outside the SPLN standard. Bus 9 is identified as experiencing a significant voltage drop. Therefore. SVC will be installed at this bus. The DG rating to be installed is according to equation (6).

D. Power Flow After Adding SVC at Bus 9

By installing SVC at Bus 9. all buses experience an improvement. and no bus falls outside the standard. The placement on Bus 9 leads to a good improvement. with Bus 14. previously outside the tolerance limit. now within the PLN tolerance limits. and several buses previously at critical limits now within marginal limits. The improvement can be seen in Table IX.

E. Power Flow After Adding DG at Bus 9

By installing DG at Bus 9. all buses experience an improvement. and no bus falls outside the standard. Placement at Bus 9 results in a significant enhancement in voltage levels. The improvements can be seen in Tabel X.

TABLE VI. SVC RATING

BUS	Nominal (kV)	Q1 before SVC installation (MVAR)	Desired Q2 with PF is 0.999	Qsvc to be installed
Bus 9	13.80	17.37	1.38	15.93

TABLE VII. DG RATING

BUS	Nominal (kV)	Rating DG (MW)
Bus 9	13.80	20.58

TABLE VIII. EXISTING CONDITIONS

BUS ID	Nominal (Kv)	Voltage (%)	Rated (kV)	Tolerance Limit -10% (kV)	Tolerance Limit +5% (kV)
Bus 1	69.00	100.00	69.00		
Bus 2	69.00	96.60	66.65		
Bus 3	69.00	91.04	62.81	62.1	72.45
Bus 4	69.00	91.54	63.16		
Bus 5	69.00	92.20	63.61		
Bus 6	13.80	94.23	13.00	12.42	14.49
Bus 7	13.80	93.10	12.84		
Bus 8	18.00	96.29	17.33	16.2	19.8
Bus 9	13.80	91.04	12.56		
Bus 10	13.80	89.70	12.37		
Bus 11	13.80	92.02	12.69	12.4	14.49
Bus 12	13.80	92.33	12.74		
Bus 13	13.80	91.65	12.64		
Bus 14	13.80	89.11	12.29		

F. Comparative Analysis

When SVC and DG are installed on each bus. it is evident that both devices can effectively improve voltage levels. It is observed that placing the devices at Bus 9 and Bus 14 can bring voltage within SPLN limits. From the three buses sampled for input. it was found that Bus 9 shows the best improvement when SVC/DG is installed. All buses exhibit significant improvements. This indicates that the primary criterion for the application of DG and SVC is the placement of the devices on the low-voltage side and around critical buses [25]. Additionally. the load of a bus and its surrounding buses will also affect the placement effectiveness [26].

TABLE IX. VOLTAGE PROFILE OF BUS 9 (SVC)

BUS ID	Nominal (kV)	Voltage (%)	Improvement (kV) Before	Improvement (kV) After	Tolerance 10% (kV)	Tolerance -5% (kV)
Bus 1	69.00	100.00	69.00	69.00		
Bus 2	69.00	97.07	66.65	66.97		
Bus 3	69.00	91.87	62.81	63.38	62.10	72.45
Bus 4	69.00	92.61	63.16	63.90		
Bus 5	69.00	93.14	63.61	64.26		
Bus 6	13.80	96.03	13.00	13.25	12.42	14.49
Bus 7	13.80	95.20	12.84	13.13		
Bus 8	18.00	98.32	17.33	17.69	16.20	19.80
Bus 9	13.80	93.69	12.56	12.92		
Bus 10	13.80	93.23	12.37	12.86		
Bus 11	13.80	94.20	12.69	12.99	12.42	14.49
Bus 12	13.80	94.23	12.74	13.00		
Bus 13	13.80	93.62	12.64	12.91		
Bus 14	13.80	91.52	12.29	12.63		

TABLE X. VOLTAGE PROFILE BUS 9

BUS ID	Nominal (kV)	Voltage (%)	Improvement (kV) Before	Improvement (kV) After	Tolerance -10% (kV)	Tolerance +5% (kV)
Bus 1	69.00	100.00	69.00	69.00		
Bus 2	69.00	97.543	66.65	67.31		
Bus 3	69.00	92.533	62.81	63.85	62.10	72.45
Bus 4	69.00	93.411	63.16	64.46		
Bus 5	69.00	93.846	63.61	64.76		
Bus 6	13.80	96.101	13.00	13.26	12.42	14.49
Bus 7	13.80	95.501	12.84	13.18		
Bus 8	18.00	98.609	17.33	17.75	16.2	19.8
Bus 9	13.80	93.620	12.56	12.92		
Bus 10	13.80	93.205	12.37	12.86		
Bus 11	13.80	94.250	12.69	13.00		
					12.42	14.49
Bus 12	13.80	94.250	12.74	13.01		
Bus 13	13.80	93.693	12.64	12.93		
Bus 14	13.80	91.515	12.29	12.63		

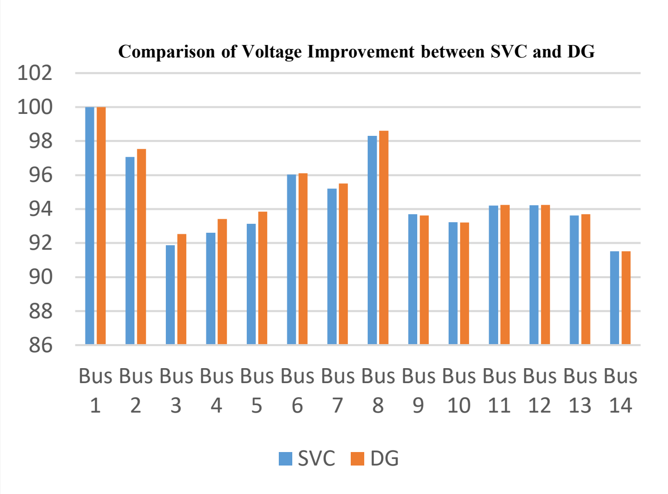

Figure 1. Comparison Graph of SVC and DG on Voltage

TABLE XI. COMPARISON OF POWER LOSSES AT BUS 9

After Installation (MW)	
SVC	17.90
DG	14.70

Figure 1. shows that DG performs better than SVC. although the difference is not very significant. Moreover. the voltage drop from SVC and DG also affects power losses. Currently. there is a power loss of 18.5 MW. and the comparison can be seen in the Table II.

From Table XI. it is evident that Distributed Generation (DG) performs better in reducing power losses compared to the Static Var Compensator (SVC). There is a difference of 3.2 MW between the performance of DG and SVC. It can be concluded that DG has a superior capability in mitigating voltage drops and power losses. This can be attributed to the following reasons:

First. the operating mechanism of DG involves the injection of both active and reactive power. In addition to injection. DG can also absorb reactive power [14]. Conversely. SVC functions by absorbing and generating reactive power (MVar) through the regulation of the thyristor firing angle [7]. One way to reduce power losses and enhance voltage profiles is to manage the availability of reactive power [27]. DG's operational mechanism allows for better control over the amount of available reactive power because DG can both inject and absorb reactive power. Second. DG has a significant advantage when placed on the load side of a bus. This is because placing DG on the load side increases the conductor capacity of the DG. These two factors make DG more efficient than SVC.

IV. CONCLUSION

From the discussions and research conducted. the following conclusions are drawn; The installation of SVC and DG can improve voltage profiles. After the installation of SVC/DG. the voltage profiles of each bus meet the allowable voltage standards set by PLN. The installation of SVC with a rating of 15.99 MVAR and DG with a rating of 20.58 MVAR at bus 9 results in the most significant voltage improvement and power loss reduction. All buses meet the PLN standards when installed at bus 9. Bus 9 has the lowest rating of 91.525 % for SVC and 91.515% for DG. DG demonstrates better performance in increasing voltage compared to SVC. with a difference of 0.16% at the lowest point of bus 9. DG also shows superior performance in reducing power losses. with a difference of 3.2 MW. or 17.3%. at bus 9.

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