Study of the placement of STATCOM in the South Sulawesi transmission system after the integration of PLTB Sidrap and Jeneponto

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Study of the Placement of STATCOM in the South Sulawesi Transmission System after the Integration of PLTB Sidrap and Jeneponto

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Abstract. The wind or wind power used by the PLTB has a speed that is not always constant. The possibility of wind speed fluctuations is inevitable and should not be underestimated. This certainly affects the stability of the system when the two PLTBs, namely the Sidrap and Jeneponto PLTBs enter the Sulselbar interconnection system. To keep the voltage in the system normal, equipment is needed to overcome the voltage drop that occurs in the system. In this study, the Static Synchronous Compensator (STATCOM) was used as a voltage regulator. STATCOM can generate reactive power and absorb reactive power according to system requirements. The system used is the Sulselbar transmission system. The software used to simulate the installation of STATCOM is PSAT 2.19 MATLAB 2014a with the power flow calculation method using the Newton Raphson method. The simulation is carried out in two different conditions, namely the normal state and the situation when there is a three-phase short circuit before and after the Sidrap and Jeneponto PLTB integration. The simulation results of the system in normal conditions before the PLTB integrated it obtained that bus 43 had a voltage of 249 kV after the STATCOM placement increased to 274 kV. Meanwhile, when the system experiences a problem, the voltage at bus 43 is 187 kV after placing STATCOM, the bus voltage of 43 is 273.62 kV. The simulation results of the system under normal conditions after integrating PLTB obtained that bus 43 has a voltage of 249.75 kV. Meanwhile, when the system has a three-phase fault, the voltage on bus 43 is 186.97 kV. After placing STATCOM, the voltage on bus 43 is 271.39 kV. The simulation results show that STATCOM can improve the voltage profile on each bus.

INTRODUCTION

Electrical energy is a human need that must always be fulfilled. This dependence on electrical energy cannot be separated from the times itself, where at this time all the equipment used is already using a reliable electric state, which is something that consumers always expect and always strive for by the electricity provider itself, in this case, PLN. In general, it can be said that electrical energy is one of the prerequisites for human life, and the development of human life requires an additional supply of electrical energy. Energy demand increases gradually, both in terms of capacity, quality and in terms of distribution demands. Indonesia's huge consumption of electricity will be a problem if its supply is not in line with the demand for electricity supply [1].

Renewable energy comes from natural processes and is likely to never run out. The potential for developing renewable energy in Indonesia is very large, one of the efforts to utilize renewable energy is the construction of the Bayu Power Plant (PLTB) in South Sulawesi, namely in Sidrap and Jeneponto districts. This power plant converts wind energy into electrical energy using wind turbines. This type of wind energy generation is relatively new in

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Indonesia, although wind energy generation has been used by developed countries such as the Netherlands, England, Australia and others [2--4]

The wind or wind power used by the PLTB has a speed that is not always constant. The possibility of wind speed fluctuations is inevitable and should not be underestimated[5--8]. This certainly affects the stability of the system when the two PLTBs, namely the Sidrap and Jeneponto PLTBs enter the Sulselbar interconnection system[4,9,1O]. And the main cause of instability is the inability of the power system to meet the demand for active power. While the system load in the form of active power always changes all the time. To maintain the voltage within the allowable tolerance limits, the active power supply (generator) must always be adjusted to the active power load [8,11]

To keep the voltage in the system normal, equipment is needed to overcome the voltage drop that occurs in the system. One way to maintain the stability of the system is by adding Static Synchronous Compensator (STATCOM) equipment to the electric power system.

Based on the background described above, it will simulate the effect of installing a Static Synchronous Compensator (STATCOM) on the Sulselbar power system to improve voltage stability due to the entry of the Sidrap and Jeneponto PLTBs.

THEORETICAL BASIS

Stability of the Electric Power System

Electric power system stability is defined as the ability of an electric power system to maintain normal conditions and be able to return to normal conditions after a disturbance occurs [4] . Disturbances in the electric power system are divided into two, namely, minor disturbances and major disturbances. Minor disturbances in the form of load changes occur continuously and the system adapts to changing conditions. The system must be able to operate under every condition satisfactorily and according to the load demands. In addition, the system must also be able to withstand several major disturbances from inside and outside the system, including short circuits on transmission lines or loss of a large generator [12].

The response of the electric power system to interference can affect the condition of the equipment. A fault in a critical element can cause variations in power flow, line bus voltage, and engine rotor speed. Voltage variations activate the exciter on the generator, load variations activate the governor to adjust the generator speed, and voltage and frequency variations affect the system load to vary depending on each characteristic. The stability is then grouped into three parts which can be seen in Fig. 1 [12].

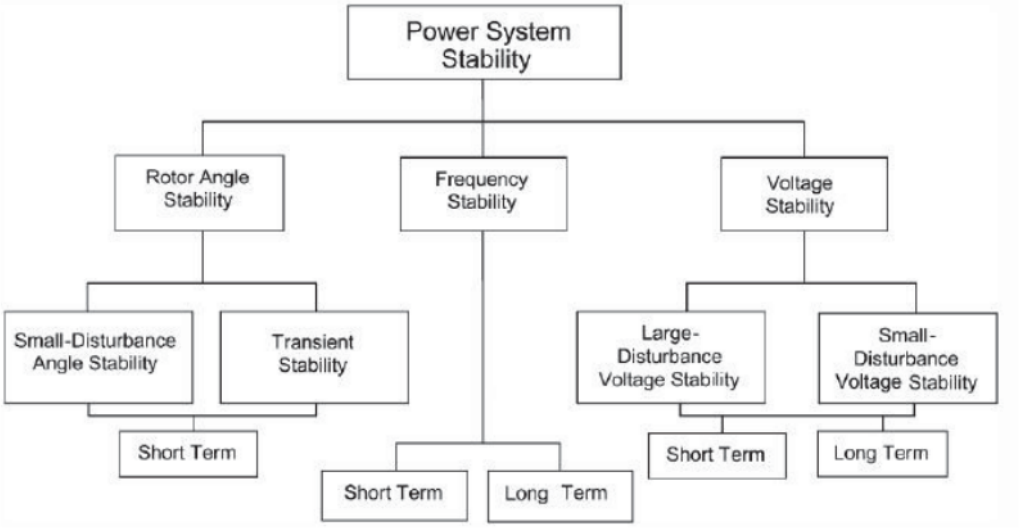

FIGURE 1. Classification of electric power system stability [11]

Voltage Stability

The voltage stability relates to the ability of an electric power system to maintain steady voltage on all buses in the system that is under normal operating conditions after experiencing a disturbance. The instability may occur in the form of a progressive increase or decrease in voltage across multiple buses. The result of stress instability is load loss in areas where the stresses reach unacceptably low values. The main factor affecting voltage instability is the voltage drop that occurs when active power flows and reactive power through the inductive reactance of the transmission line [13--15].

This limits the ability of the transmission network to transmit power. Power transfer is further limited when some generators reach their limit of reactive power capability. Voltage stability is seriously threatened when the demand for reactive power exceeds the capacity of reactive power available from the source. The voltage stability is also divided into two categories, namely the stability of the large noise voltage and the stability of the small noise voltage. The time range for voltage stability issues varies from a few seconds to a few minutes. Thus, the voltage stability may be a long-term or a short-term phenomenon [16--2O].

STATCOM

STATCOM is categorized as a new technology in the field of reactive power compensators. STATCOM is able to produce small harmonic values and controllable AC voltage values as its output. These values can affect reactive power values. Besides that, STATCOM is also able to compensate for several other problems such as flicker, mains impedance in the transmission system, and phase angle differences [21].

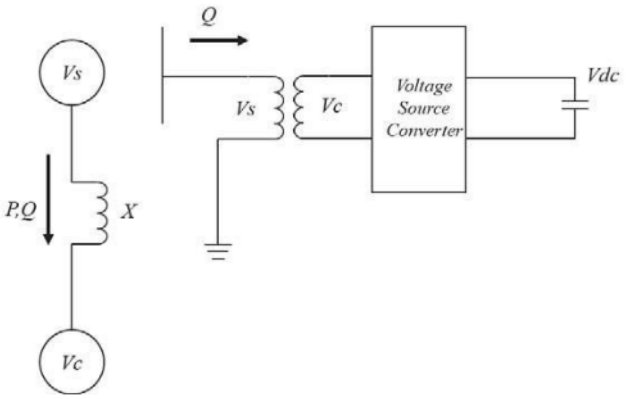

FIGURE 2. The working principle of the STATCOM system [8]

Reactive power control by STATCOM occurs by comparing the value of the terminal voltage between STATCOM and the system. If the STATCOM voltage is lower, STATCOM will absorb the reactive power in the system. If the value is higher than the system, it will generate reactive power to the system [21].

The working principle of STATCOM is shown in Fig. 2 and described in Eqs. (1), (2), and (3) which show the active and reactive power delivery between *Vs* Grid and *Vc* STATCOM [8] .

$$P = \frac{V_S V_C \sin o}{X_L} \quad (1)$$

$$Q = \frac{V_S \left(V_S - V_C \right) \sin o}{X_L} \quad (2)$$

$$S = 3 \frac{V_S V_C \sin o}{X_L} - j3 \left(\frac{V_S V_C}{X_L} \cos o - \frac{V_S^2}{X_L} \right) = P - jQ \quad (3)$$

where,

S = Power complex (VA),
V_C = Statcom terminal voltage,
V_S = Voltage from the Grid / System,
P = Active Power (W)
Q = Reactive power (Var),
X_L = Reactance
$<$ = Phase difference between V_S and V_C

From the above equation, it is explained that variations affect the flow of active power between the system and STATCOM. With the lagging value, the active power flows from STATCOM to the grid. When the value is leading, the active power will be absorbed into STATCOM. If the grid condition has the same phase as STATCOM, the active power will be zero ($P = 0$). Value = 0, obtained when the system is in steady state [21].

The active power flow reaches its maximum when the phase angle is 90°. In practice, the power factor should be above 0.85 to 0.9 so that the power angle is small (about 25°). This is intended to keep the system stable from transients and dynamic oscillations. Therefore, the power angle has a direct effect on the active power flow (Eq. 1) while the reactive power flow is affected by the change in voltage between buses, because cos < approaches 1 (Eq. 2).

In conditions where there is no compensation, a typical transmission line is an inductive load where the current is lagging against the voltage. The system load line is illustrated in Fig. 3, if the system load is more inductive, the current is lagging behind while Q is also greater, meaning that it absorbs more reactive power, on the contrary, if it is more capacitive, the current leads to voltage V and supplies reactive power Q.

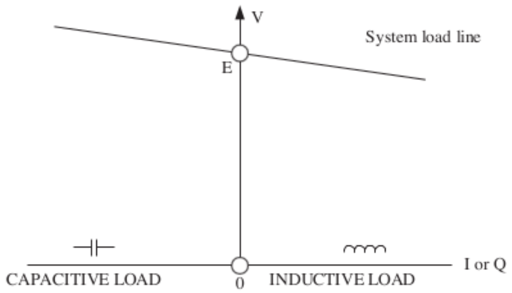

FIGURE 3. System load line

Main Components of STATCOM

STATCOM basically consists of four main components, namely:

1) Voltage Source Converter (VSC)
2) Transformer Coupling
3) Controller
4) DC energy storage

Voltage Source Converter (VSC)

VSC is a power electronic device capable of producing sinusoidal voltages with the desired frequency, magnitude and phase angle. By converting the DC voltage on the storage device into a set of three-phase AC output voltages. The voltage is in phase and coupled with the AC system via the reactance of the coupling transformer. VSC functions as a rectifier when STATCOM absorbs reactive power from the system and inverter when STATCOM supplies reactive power to the system. The voltage lost in this case is the difference between the nominal and actual voltages. VSC is usually based on some type of energy storage supplying the DC voltage and the desired voltage is then obtained by switching solid-state electronic devices in converter circuits [9,15].

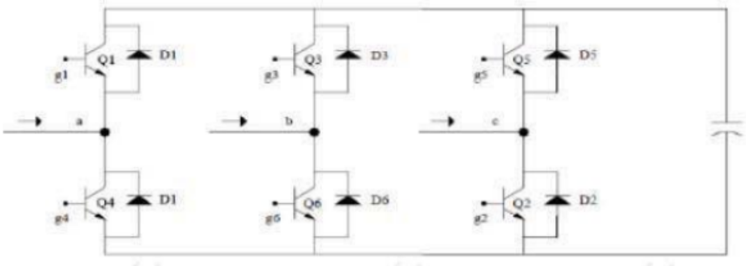

FIGURE 4. Three phase voltage source converter

Transformer Coupling

Transformer couplings are needed to lower the system voltage to match the utility grid. A coupling reactor is usually combined in order to filter out the harmonic current components generated by the output voltage spike from the VSC. The difference in the leakage reactance of the AC voltage results in a mutual exchange of power between STATCOM and the electric power system, thus that the AC voltage in the bus bar can be adjusted to increase the voltage profile of the power system, which is the main task of STATCOM. Alternatively, a secondary damping function can be added to STATCOM to increase the stability of the power system oscillations.

Controller

The controller performs feedback and output control in a set of voltages affecting the signal to drive the semiconductor master switch of the power converter. This generates a signal transfer at STATCOM which is used to activate STATCOM in injecting reactive current into the grid to act as an over-excited synchronous generator (or capacitor) thereby increasing the grid voltage or absorbing reactive current and behaving like an under-excited synchronous generator (or inductor) which tends to lower grid voltages.

The main function of the controller is to keep the voltage constant at the sensitive load point connected under system disturbances. This is done by measuring and comparing the r.m.s voltage at the load point with the reference voltage. The difference between the two values is the error signal which serves as input to the controller. The output is the power angle provided for the PWM signal generator. Thus, the processed error signal produces the desired power angle, directing the error to zero, thus restoring the r.m.s value of the load voltage with the reference voltage value.

DC Energy Sources

The DC voltage source can be provided by the capacitor connected on the DC side of the VSC. The DC energy source is connected in parallel with a DC capacitor. This carries the input ripple current from the converter. The capacitor can be charged by VSC. VSC's function is to support real resources under fluctuating power conditions. Thus, in order to achieve the required voltage regulation, the VSC is connected in parallel with the DC capacitor from STATCOM thus making it an energy storage element. The VSC will then inject or absorb the reactive power needed to stabilize the grid system while maintaining a constant DC capacitor. In other words, it charges and discharges to improve the voltage profile. Thus, the DC energy store is responsible for providing and absorbing the real power that is being exchanged by the transmission system at its DC terminal.

STATCOM VOLTAGE REGULATION

STATCOM is a Voltage-Source Inverter (VSI), which converts DC input voltage into AC output voltage to compensate for the active and reactive power required by the system. The basic operating principle of a reactive power generator with VSI is similar to that of a conventional synchronous machine. The reactive current drawn by the synchronous compensator voltage depends on the magnitude of the system voltage *V*, namely the *Vo* converter and the reactance of the whole circuit (transformer leakage reactance plus transformer coupling reactance) *X*:

$$I = \frac{V - V_O}{X} \tag{4}$$

The exchange of reactive power Q is expressed by:

$$Q = \frac{1 - \frac{V_O}{V}}{X} V^2 \tag{5}$$

So, the KVAR determination from STATCOM is done with the formula:

$$Q = V \quad S_{SC} \tag{6}$$

where ,

Q = Compensator Capacity
V = voltage fluctuations
S_{sc} = Short Circuit KVA [22]

RESEARCH METHODS

The methodology used in the thesis of STATCOM Placement Study on the Transmission System of South Sulawesi after the entry of PLTB Sidrap and Jeneponto is: The data taken is secondary data from PT. PLN (Persero) Main Unit for Generation and Distribution of the Sulselrabar Region which consists of generation and loading data, impedance data, and single line diagrams.

This study aims to determine how the response of STATCOM placement in each system condition in the Sulselbar transmission system. The scenarios carried out in this study are:

Scenario 1 : Simulation of the power flow of the Sulselbar system when the system is in normal condition (before the Sidrap and Jeneponto PLTB). Based on the one-line diagram and system data, the power flow simulation results are carried out in order to determine the initial condition of the system before analyzing the stability of the power system.

Scenario 2 : Simulation is performed when the system is in normal condition (before the Sidrap and Jeneponto PLTB) by placing STATCOM. This simulation is done to find out how STATCOM responds in improving voltage stability

Scenario 3 : Simulation is carried out when the system is given a fault in the form of a three-phase short circuit on the Palopo bus. The determination of the three-phase short circuit fault is based on a blackout case that occurred in November 2O18, where this short circuit disturbance occurred on the 15Okv Makale-Palopo transmission line which allegedly occurred due to bad weather, causing blackout for several hours. The purpose of this simulation is to see how the system voltage is when a three-phase short circuit occurs.

Scenario 4 : This simulation is performed when the system is given a three-phase fault on a system using STATCOM. This simulation is carried out to see how STATCOM improves voltage stability or minimizes voltage drop when a disturbance occurs.

Scenario 5 : This simulation is carried out when the Sulselbar system is integrated with PLTB Sidrap and Jeneponto with varying output power and dynamics occur. The dynamics referred to here are when the plant operates in normal and maintenance conditions. So that from these conditions we can see the voltage profile on all buses in the system so that they remain within the voltage tolerance limits.

Scenario 6 : This simulation is carried out when placing STATCOM in the Sidrap and Jeneponto PLTB integrated pulse system with varying output power when there is a three-phase short circuit on the Palopo bus.

RESULTS AND DISCUSSION

Normal Condition Voltage Profile

The STATCOM placement simulation was carried out on Bus 43 which is located at GI Latuppa 275kV. This is done because after the initial simulation, bus 43 is the bus with the lowest voltage or close to the PLN voltage tolerance limit of + 5% to -1O%.

$$Q = \;V \;\; S_{SC}$$

$$S_{SC} = S_{base} \xi \frac{100}{x\%}$$

$$= 100MVA \xi \frac{100}{52.504} = 190.4617MVA$$

For capacitive reactive power limit �$V = 5\%$

$$Qc = \;V \;\; S_{SC}$$

$$= 0.05 \xi 190.4617 = 9.523 \text{ Mvar}$$

$$Xc = \frac{V^2}{Qc}$$

$$= \frac{275^2}{9.523} = 7941.230 = 10.50\,pu$$

then the capacitive current limitation is:

$$\mathrm{I}_{\max} = B \xi V$$

$$= \frac{1}{X_c} \xi 1 = 1.3\,pu$$

Whereas for the inductive reactive power limit �$V = 1\%$

$$Q_L = \;V \xi S_{SC}$$

$$= 0.01 \xi 190.4617$$

$$= 1.9046MVAR$$

$$X_L = \frac{V^2}{Q_L}$$

$$= \frac{275^2}{1.9046}$$

$$= 39706.150 = 52.504\,pu$$

$$Q_L = \;V \xi S_{SC}$$

$$= 0.01 \xi 1.10$$

$$= 0.011MVAR$$

$$X_L = \frac{V^2}{Q_L}$$

$$= \frac{0.4^2}{0.011} = 14.50 = 3.6\,pu$$

Then for the inductive current limitation is:

$$I_{\min} = B\xi V$$
$$= \frac{1}{X_L}\xi 1 = 0.02\,pu$$

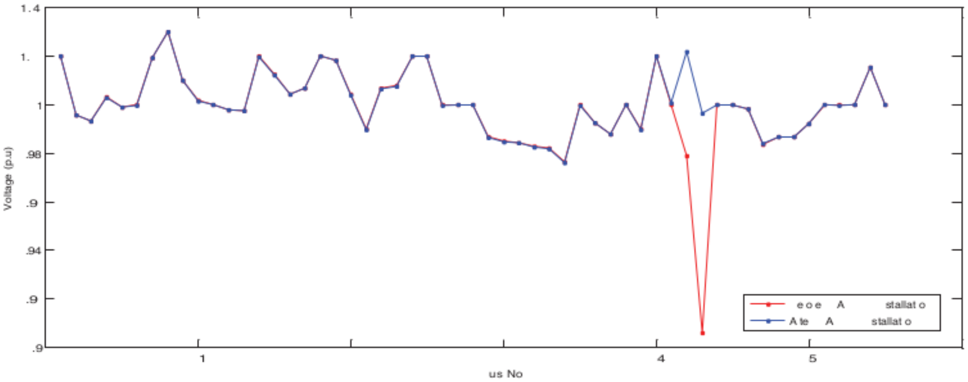

FIGURE 5. Comparison of voltage before installing STATCOM and after installing STATCOM in normal conditions

From Fig. 5, it can be seen the change in voltage on each bus when Bus 43 is paired with STATCOM. The voltage on Bus 43 is 249 kV while after placing STATCOM the voltage on Bus 43 is 274 kV. This shows that the installation of STATCOM can increase the voltage profile by 1O.O4%.

Voltage Profile when Failure Occurs

The purpose of this simulation is to see how the system voltage is when there is a three-phase short circuit and see the response of STATCOM in improving the voltage profile. Short circuit fault simulations were carried out once on the Palopo Bus (Bus 41).

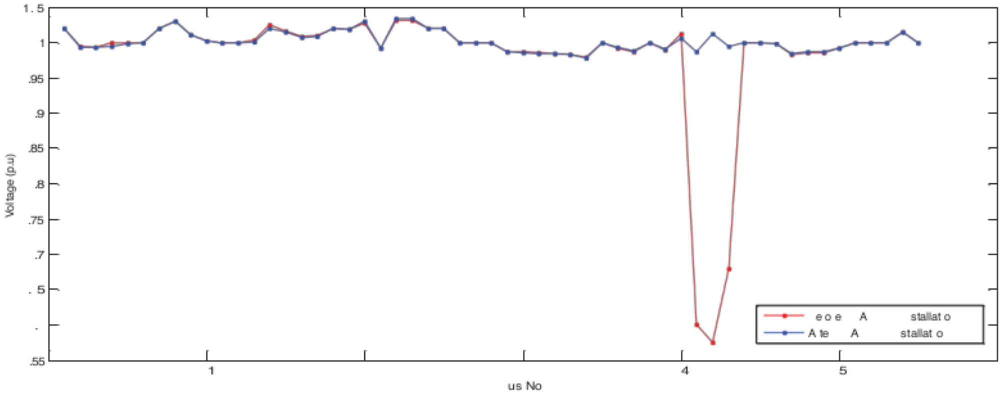

FIGURE 6. Voltage Comparison before STATCOM installation and after STATCOM installation when a three-phase fault occurs on bus 41

From Fig. 6, it can be seen that when the system experiences a problem the voltage on bus 43 is 187 kV after placing STATCOM, the bus voltage of 43 is 273.62 kV. The simulation results show that STATCOM can increase the voltage profile on each bus by 46.3%.

Voltage Profile under Normal Conditions when PLTB Sidrap is Integrated with Variable Output Power

The next simulation is carried out. In normal conditions (integrated Sidrap PLTB), the simulation is carried out in normal conditions after the Sidrap PLTB is integrated to see the initial voltage profile with varying output power. This variable output power is carried out with 4 simulations, namely with an output power of 25%, an output power of 5O%, an output power of 75%, and an output power of 1OO% or 75 MW. The voltage response on each bus can be seen in Fig. 7.

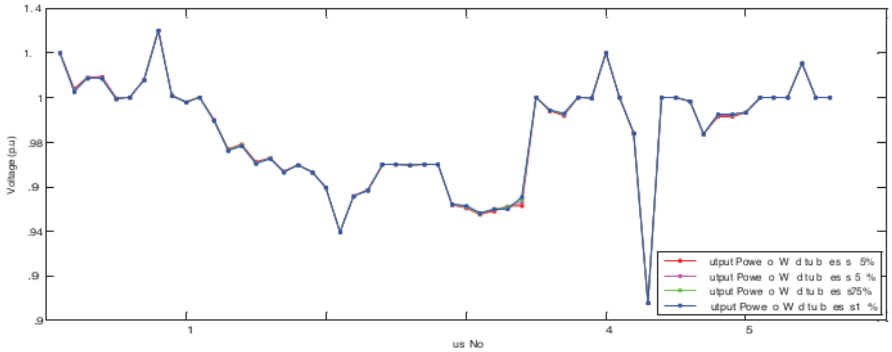

FIGURE 7. Comparison of voltages under normal conditions when the Sidrap PLTB is integrated with variable output power

Voltage Profile under Normal Conditions when PLTB Jeneponto is Integrated with Variable Output Power

The next simulation is carried out. In normal conditions (integrated Jeneponto PLTB), the simulation is carried out in normal conditions after the Jeneponton PLTB is integrated to see the initial voltage profile with varying output power. This variable output power is carried out with 4 simulations, namely with an output power of 25%, an output power of 5O%, an output power of 75%, and an output power of 1OO% or 72 MW. The resulting voltage response on each bus can be seen in Fig. 8.

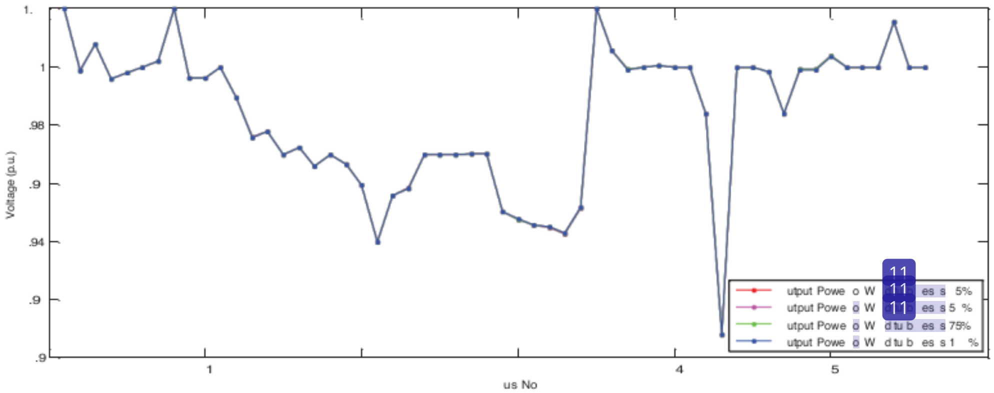

FIGURE 8. Comparison of voltage under normal conditions when the Jeneponto PLTB is integrated with variable output power

CONCLUSION

During normal conditions before placing STATCOM the voltage on Bus 43 was 249 kV, while after placing STATCOM the voltage on Bus 43 was 274 kV. This shows that the installation of STATCOM can increase the voltage profile by 1O.O4%. Simulated three-phase short circuit fault on Bus 41 before placing STATCOM causing voltage drops on several buses, namely bus 41, bus 42 and bus 43. Bus 41 has a voltage of 9O kV, bus 42 has a voltage of 86.25 kV and bus 43 has a voltage of 187kV. Meanwhile, after the placement of STATCOM, the bus that experienced a voltage drop now has a voltage value on each bus 41, 42, and 43, namely O 147.94 kV, 151.95 kV, and 273.62 kV which are already at the limit of PLN voltage tolerance. The simulation results show that STATCOM can increase the voltage profile on each bus by 64.3%, 76.1% and 46.3%. Changes in the output power generated by PLTB Sidrap and Jeneponto after being integrated with the Sulselbar system do not affect the stability of the existing voltage. A significant change in voltage occurs only on a few buses and the other bus voltages are constant, but still within the allowable voltage tolerance limits. Simulated three-phase short circuit fault on Bus 41 before placing STATCOM after the PLTB is integrated with variable output power causing voltage drop on several buses, namely bus 41, bus 42 and bus 43 as well. Each bus 41, 42 and 43 with varying output power has a voltage of 98.83 kV, 88.485 kV, and 186.97 kV. Meanwhile, after the placement of STATCOM, the bus that experienced a voltage drop now has a voltage value on each bus 41, 42, and 43, namely 147.43 kV, 146.11 kV, and 271.39 kV which are already at the limit of PLN's voltage tolerance. The simulation results show that STATCOM can increase the voltage profile on each bus by 49.1%, 65.1% and 45.1

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GRADEMARK REPORT

FINAL GRADE

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GENERAL COMMENTS

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