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Study of Distributed Static Compensator (D-STATCOM) Installation in Makassar Electrical Energy Distribution System

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Abstract. In supporting the economic growth of a region, the role of industry is needed. The smooth running of an industry cannot be separated from the existing electrical quality, in this case, the voltage drop. The voltage drop occurs because of the influence of the load and the distance of the distribution channel which is quite far. To minimize the voltage drop that occurs, a voltage regulator that works automatically is required. In this study, Distributed Static Compensator (D-STATCOM) was used as a voltage regulator. D-STATCOM can generate reactive power and absorb reactive power according to system requirements. The system used is the Kima feeder distribution system, which is an area with many industries. The software used to simulate the installation of D-STATCOM is PSAT MATLAB 2.1.9. The simulation is carried out in two different conditions, namely the normal state and the state when there is a three-phase short circuit fault. The simulation results under normal conditions obtained that bus 73 has a voltage of 0.90302 pu after the installation of D-STATCOM increases to 0.94597 pu. Meanwhile, when the system experiences a problem, the voltage on bus 73 is 0.89790 pu. After the installation of D-STATCOM, the 73 bus voltage is 0.94010 pu.

INTRODUCTION

Along with the times, the use of electrical energy is also increasing. The greater the electrical energy required, the greater the electrical system required. Prof. Iwa Garniwa Mulya, Professor of the Faculty of Engineering, University of Indonesia, said that electricity is an important infrastructure in supporting economic growth, encouraging investment, and industrial equity, which has a further impact on job creation and regional economies [1,2].

However, in distribution, there are various kinds of problems such as an imbalance in the distribution system which is influenced by the type of load. Capacitive loads which store voltage temporarily, tend to result in the network voltage value being higher than it should be. Meanwhile, inductive loads that absorb electric current tend to decrease the grid voltage [3,4].

Voltage drop is the amount of voltage lost in a conductor which can occur because a conductor has resistance. The resistance of a conductor is strongly influenced by the cross-sectional area of the conductor. Therefore, long-distance distribution and the density of the population make it possible for the voltage drop to occur. As a result of the voltage drop, the power losses are getting bigger which is directly detrimental to PT. PLN (Persero) as a provider of electricity in Indonesia. The voltage drop cannot be eliminated, but can only be minimized (reduced). The method to maintain voltage stability in the distribution network under study is the application of the Distributed Static Compensator (D-STATCOM) [5,6,7].

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D-STATCOM can produce inductive and capacitive variables continuously up to the maximum MVA rating level. By checking the waveform of the line with respect to the AC signal source, D-STATCOM can compensate for both leading and lagging currents when there is voltage fluctuation [8,9,10].

Based on the background described above, a study entitled Distributed Static Compensator (D-STATCOM) Installation Study in Makassar Electrical Energy Distribution System was conducted.

THEORETICAL BASIS

Voltage Stability

Voltage stability refers to the ability of a power system to maintain a stable voltage on all buses in the electric power system after a disturbance has occurred from the given initial operating conditions. This depends on the ability to maintain/restore the balance between the load demand and the load supply of the power system [11,12,13,14,15].

The instability may occur as the result of a progressive decrease or rise in voltage of several buses, from the result of voltage instability to loss of loads in the area or to tripping of transmission lines and other elements. Frequency instability can result in a decrease or increase in the voltage of some buses [16,17].

P – V Curves

The P-V curve is very useful for conceptual analysis of stability and stress for a system, where P is the total load and V is the critical or bus representative voltage. P can also transfer power between transmissions or interconnects. The voltages on several buses can be plotted. For conceptual analysis, the P-V curve is convenient when the load characteristics are a function of stress [18]. To see the characteristics of the P - V curve it can be seen in Fig. 1.

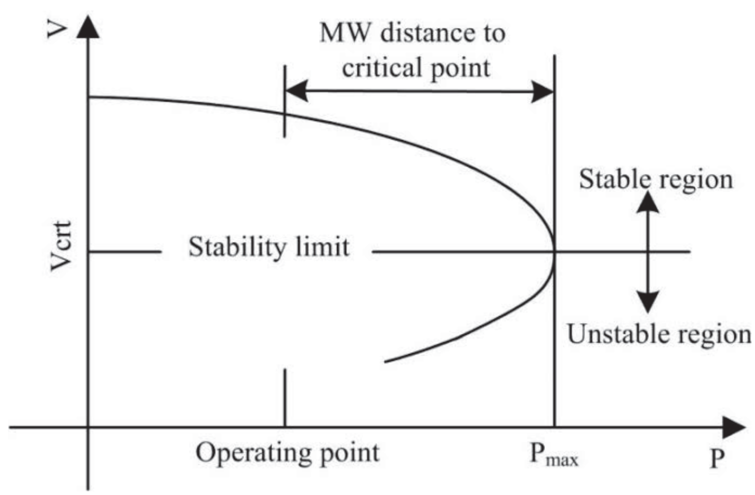

FIGURE 1. P-V curve

This connection point expresses the load performance giving steady, for a linear strainline stability circuit, while the peak critical point expresses the stable operating conditions and the critical point expresses the instability of the operating conditions.

Curves Q -V

The stress stability analysis through the Q-V curve is to see the condition of the total load (Mvar) of the system strain towards the critical point and decreasing. This means that the system performance in reactive power delivery has exceeded the performance of the system itself. To see the characteristics of the Q - V curve can be seen in Fig. 2.

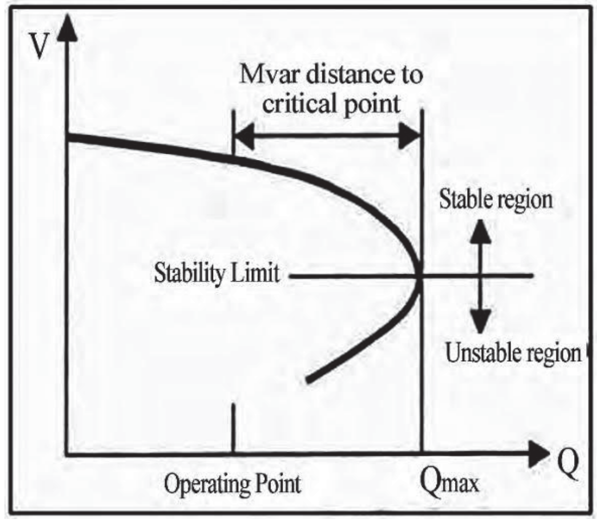

FIGURE 2. P - Q curve

This connection point expresses the load performance giving steady-state for the linear strainline stability circuit, whereas above the critical point expresses the stable operating conditions and below the critical point expresses the unstable operating conditions.

D-STATCOM

Distribution Static Compensator (D-STATCOM) is a voltage inverter source as a static compensator used to correct voltage deflection. The distribution network connection is done parallel (shunt) connected through a power distribution transformer. D-STATCOM can produce inductive and capacitive variable parallel compensation continuously at the maximum rating level of MVA [10,19]. D-STATCOM checks the waveform of the line with respect to the reference AC signal and can therefore provide the correct amount of leading or lagging compensating current to reduce the amount of voltage fluctuation.

Model D-STATCOM

The general form of the Distribution Static Compensator consists of a combined two VSC levels, a DC source and the combining transformer connected in a shunt manner to an alternating current system and a connected control unit. The shape can be designed more sophisticatedly using multi-pulse or multi-level configuration [20].

The main components of D-STATCOM consist of a dc capacitor, one or more inverter modules, an AC filter, a transformer to match the inverter output to the line voltage, and a PWM control. In the D-STATCOM implementation, a voltage inverter source converts a three-phase AC DC voltage and is connected to the AC line through the reactor and capacitor bonds. Figure 3 shows the block diagram of D-STATCOM.

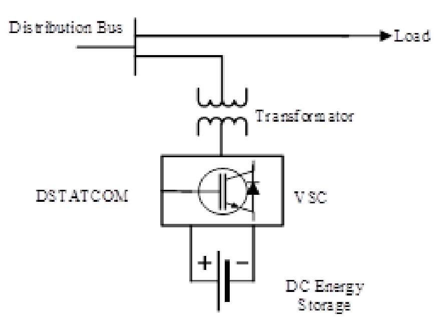

FIGURE 3. D-STATCOM block diagram

The D-STATCOM component consists of three main components, namely:

- IGBT or GTO-based DC to AC inverter: This inverter is used to create a leading or lagging active current in the voltage output wave which is controlled in magnitude and phase based on the required compensation.
- L-C filter: LC filters are used to reduce harmonics and match the inverter output impedance to enable multi-parallel inverters to divide the current. The LC filter was chosen because of its compatibility with the type of system and the harmonics that occur in the converter output.
- Control Block: Controller controls are used when Pure Wave D-STATCOM module switches are required. The controllers can control external equipment such as capacitor bank mechanical switches.

D-STATCOM Voltage Regulation

D-STATCOM is a Voltage-Source Inverter (VSI), which converts the DC input voltage to the 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:

$$I = \frac{V-Vo}{X} \tag{1}$$

The exchange of reactive power Q is expressed by:

$$Q = \frac{1\frac{Vo}{V}}{X}V^2 \tag{2}$$

So, the KVAR determination from D-STATCOM is done with the formula [11]:

$$\Delta Q = \Delta V * S_{sc} \tag{3}$$

where

ΔQ= Compensator Capacity
ΔV= Voltage Fluctuation
Ssc = KVA Short Circuit

Basic Operating Principles

The basic working principle of DSATCOM is the same as the synchronous machine. Synchronous engines provide lagging currents when under excitation and leading currents when overexcitation.

D-STATCOM can generate and absorb the same reactive power as synchronous machines and can swap real power if provided with an external DC source.

1) D-STATCOM exchange reactive power: Performed if the output voltage of the mains converter is greater than the system voltage. D-STATCOM works as an inductive reactance so that the equipment produces capacitive reactive power (the leading current moves from the D-STATCOM to the system) and if the output voltage of the converter is smaller than the system voltage, D-STATCOM works as a capacitive reactance so that the equipment absorbs the inductive reactive power (current lagging moves from D-STATCOM to system).
2) D-STATCOM switches real power if the switch device does not lose less real power than the DC capacitor required for switching.

Differences in D-STATCOM, Fixed Capacitor, and SVC

D-STATCOM is a voltage regulator based on FACTS (Flexible AC Transmission System) which has a very fast response of <10 ms. D-STATCOM can compensate for voltage spikes up to a high rating, in addition to having the ability to absorb and generate reactive power as required by the system because it is equipped with inductors and capacitors. Its flexible nature is advantageous for the system because of the value of reactive power that is generated or absorbed according to system requirements.

D-STATCOM is also equipped with a transformer and power control so that the need is large enough for installation [12]. Fixed Capacitor is a non-FACTS based voltage regulator which can only generate reactive power for the system. The fixed capacitor value, which means the reactive power supplied to the system is not in accordance with the system's needs and allows overvoltage to occur. Static VAR Compensator is a FACTS device that can generate reactive power and absorb reactive power. SVC includes a fast-acting reactive power compensator for high voltage transmission networks [4].

RESEARCH METHODS

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

Scenario 1: Simulation of the Kima distribution system power flow when the system is in normal or steady-state conditions. 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: The second simulation is done when conditions are still normal by placing D-STATCOM. This simulation is done to see how D-STATCOM responds in improving the voltage profile.

Scenario 3: This third simulation is when the system is given a fault in the form of a three-phase short circuit. The purpose of these simulations is to see how the system voltage is when a fault occurs.

Scenario 4: The last simulation is a simulation when there is a disturbance in the system using D-STATCOM. This simulation was conducted to see how D-STATCOM minimizes voltage drop when a disturbance occurs.

RESULTS AND DISCUSSION

Normal Condition Voltage Profile

The D-S TATCOM installation simulation was carried out on Bus 73 which is located at PT. The Great Pyramid of Magic. This is done because PT. Pyramid Megah Sakti is an active industry which is located far from the slack bus which allows a very large voltage drop.

$$\Delta Q = \Delta V \ x \ S_{sc}$$

$$S_{Sc} = S_{base} x \frac{100}{x\%} = 100 \ MVA \ x \ \frac{100}{9077.26} = 1.10 \ MVA$$

For capacitive reactive power limit Δ V = 5%

$$\Delta Q_C = \Delta V \ x \ \mathrm{S_{SC}} \ = 0.05x \ 1.10 = 0.055 \ Mvar$$

$$X_c = \frac{V^2}{Q_C} = \frac{0.4}{0.005} = 2.9 \ \Omega = 0.72 \ pu$$

then the capacitive current limitation is:

$$I_{max} = B \ x \ V = \frac{1}{X_c} x \ 1 = 1.3 \ pu$$

Whereas for the inductive reactive power limit Δ V = 1%

$$\Delta Q_L = \Delta V \ x \ S_{SC} = 0.01x \ 1.10 = 0.011 \ MVAR$$

$$X_L = \frac{V^2}{Q_L} = \frac{0.4^2}{0.011} = 14.5\Omega = 3.6 \ pu$$

Then for the inductive current limitation are:

$$I_{min} = BxV = \frac{1}{\mathrm{X_L}} \mathrm{x} \ 1 = 0.27pu$$

TABLE 1. Voltage profile when failure occurs

Bus Name	V [pu] Before D-STATCOM	V [pu] After D-STATCOM
Bus 01	1.00000	1.00000
Bus 10	0.98328	0.98333
Bus 11	0.99977	0.99982
Bus 12	0.96604	0.96609
Bus 13	0.99981	0.99986
Bus 14	0.99980	0.99985
Bus 15	0.99971	0.99976
Bus 16	0.99977	0.99992
Bus 17	0.99975	0.99993
Bus 18	0.99967	0.99995
Bus 19	0.99971	0.99999
Bus 02	0.99997	0.99997
Bus 20	0.96597	0.96626
Bus 21	0.99974	1.00002
Bus 22	0.99974	1.00002
Bus 23	0.99974	1.00002
Bus 24	0.96600	0.96629
Bus 25	0.99975	1.00003
Bus 26	0.99975	1.00003
Bus 27	1.00407	1.00437
Bus 28	1.00406	1.00436
Bus 29	0.99957	0.99991
Bus 03	0.99981	0.99984
Bus 30	0.99950	0.99984
Bus 31	0.99949	0.99983
Bus 32	0.93667	0.93704
Bus 33	0.99946	0.99981
Bus 34	0.99945	0.99979
Bus 35	0.96762	0.96798
Bus 36	0.99938	0.99972
Bus 37	0.99937	0.99971
Bus 38	0.96754	0.96790
Bus 39	0.99934	0.99969
Bus 04	0.99975	0.99978
Bus 40	0.99934	0.99968
Bus 41	0.96559	0.96595
Bus 42	0.90659	0.90697
Bus 43	0.99949	0.99991
Bus 44	0.99949	0.99990
Bus 45	0.93265	0.93310
Bus 46	0.99946	0.99990
Bus 47	0.99943	0.99988
Bus 48	0.99942	0.99987
Bus 49	0.97933	0.97979
Bus 05	0.99970	0.99973
Bus 50	0.99942	0.99987

Bus Name	V [pu] Before D-STATCOM	V [pu] After D-STATCOM
Bus 51	0.98357	0.98402
Bus 52	0.99940	0.99990
Bus 53	0.99936	0.99989
Bus 54	0.99935	0.99988
Bus 55	0.99935	0.99988
Bus 57	0.99931	0.99987
Bus 58	0.99930	0.99986
Bus 59	0.98415	0.98471
Bus 06	0.96456	0.96460
Bus 60	0.99930	0.99986
Bus 61	0.96740	0.96798
Bus 62	0.99930	0.99986
Bus 63	0.96739	0.96797
Bus 64	0.99928	0.99987
Bus 65	0.99928	0.99986
Bus 66	0.96745	0.96805
Bus 67	0.99922	0.99986
Bus 68	0.99904	0.99975
Bus 69	0.97829	0.97902
Bus 07	0.99981	0.99986
Bus 70	0.99881	0.99961
Bus 71	0.98386	0.98468
Bus 72	0.99877	0.99959
Bus 73	0.90302	0.95622
Bus 74	0.99922	0.99986
Bus 75	0.99922	0.99985
Bus 76	0.98605	0.98669
Bus 08	0.99979	0.99984
Bus 09	0.99978	0.99982

TABLE 2. Voltage profile when failure occurs

Bus Name	V [pu] Before D-STATCOM	V [pu] After D-STATCOM	Bus Name	V [pu] Before D-STATCOM	V [pu] After D-STATCOM
Bus 01	1.00000	1.00000	**Bus 51**	0.98000	0.98030
Bus 10	0.98287	0.98291	**Bus 52**	0.99540	0.99580
Bus 11	0.99936	0.99939	**Bus 53**	0.99510	0.99550
Bus 12	0.96564	0.96567	**Bus 54**	0.99510	0.99560
Bus 13	0.99939	0.99943	**Bus 55**	0.99510	0.99550
Bus 14	0.99939	0.99943	**Bus 56**	0.96350	0.96390
Bus 15	0.99930	0.99934	**Bus 57**	0.99480	0.99520
Bus 16	0.99852	0.99862	**Bus 58**	0.99480	0.99520
Bus 17	0.99835	0.99844	**Bus 59**	0.97970	0.98010
Bus 18	0.99745	0.99753	**Bus 06**	0.96424	0.96429
Bus 19	0.99745	0.99753	**Bus 60**	0.99480	0.99530
Bus 02	0.99900	0.99980	**Bus 61**	0.96300	0.99634
Bus 20	0.96355	0.96400	**Bus 62**	0.99480	0.99520
Bus 21	0.99750	0.99754	**Bus 63**	0.96300	0.96350
Bus 22	0.99750	0.99754	**Bus 65**	0.99460	0.99500
Bus 23	0.99750	0.99754	**Bus 64**	0.99450	0.99500
Bus 24	0.96356	0.96410	**Bus 66**	0.96280	0.96340
Bus 25	0.99750	0.99754	**Bus 67**	0.99410	0.99460
Bus 26	0.99750	0.99754	**Bus 68**	0.99300	0.99390
Bus 27	1.00150	1.00210	**Bus 69**	0.00000	0.00000
Bus 28	1.00150	1.00200	**Bus 07**	0.99939	0.99943
Bus 29	0.99656	0.99710	**Bus 70**	0.99300	0.99370
Bus 03	0.99951	0.99953	**Bus 71**	0.97820	0.97890
Bus 30	0.99654	0.99700	**Bus 72**	0.99300	0.99368
Bus 31	0.99653	0.99700	**Bus 73**	0.89790	0.94010
Bus 32	0.93410	0.93460	**Bus 74**	0.99410	0.99460
Bus 33	0.99654	0.99700	**Bus 75**	0.99410	0.99460
Bus 34	0.99654	0.99700	**Bus 76**	0.98100	0.98150
Bus 35	0.96459	0.96530	**Bus 08**	0.99938	0.99941
Bus 36	0.99652	0.99658	**Bus 09**	0.99936	0.99939
Bus 37	0.99652	0.99658			
Bus 38	0.96456	0.96510			
Bus 39	0.99651	0.99656			
Bus 04	0.99940	0.99943			
Bus 40	0.99651	0.99656			
Bus 41	0.96258	0.96320			
Bus 42	0.90401	0.90440			
Bus 43	0.99620	0.99650			
Bus 44	0.99620	0.99650			
Bus 45	0.92951	0.92980			
Bus 46	0.99580	0.99620			
Bus 47	0.99580	0.99620			
Bus 48	0.99580	0.99620			
Bus 49	0.97580	0.97620			
Bus 05	0.99938	0.99942			
Bus 50	0.99580	0.99620			

CONCLUSION

In normal conditions before installing D-STATCOM, the voltage on Bus 73 is 0.90302 pu. Meanwhile, after installing D-STATCOM the voltage on Bus 73 is 0.95622 pu. This shows that the installation of D-STATCOM can increase the voltage profile by 5.89%. The simulation of the D-STATCOM installation that is carried out can maintain the voltage stability. Where in the Makassar distribution system the Kima feeder distribution system, the most optimal D-STATCOM capacity is 0.055 MVAR installed on Bus 73. Simulated three-phase short circuit fault on Bus 69 before using D-STATCOM causes the voltage on Bus 73 to drop to 0.89790 pu. Meanwhile, after the installation of D-STATCOM Bus 73 voltage is 0.94010 pu. The simulation results show that D-STATCOM can increase the voltage profile by 4.69% when there is a disturbance in the system.

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