Application of Hybridized Model of Shunt and Series Facts Controllers for Improvement of Generator Oscillation Damping Stability of Electrical Power System

Ganiyu Adedayo Ajenikoko[1], Abass Balogun[2], Isiah Gbadegesin Adebayo[3], Saheed Kolawole Ashiru[4],
Abdulbasit Oladayo Ajenikoko[5], Ayoade Benson Ogundare[6] .
[1,2,3,4]Department of Electronic and Electrical Engineering
Ladoke Akintola University of Technology
P.M.B, 4000, Ogbomoso, Nigeria.
[5]Department of Electrical and Electronics Engineering
Osun State University, Osogbo, Nigeria.
[6]Department of Electrical and Electronics Engineering
Lagos State University of Science and Technology, Ikorodu, Nigeria.
Corresponding Author: ajeedollar@gmail.com

Abstract

One of the technical solutions for improving the stability of power system is incorporation of Static Synchronous Compensators (STATCOM) and Static Synchronous Series Compensator (SSSC) controllers. However, the impact of hybridized STATCOM and SSSC on the generator damping stability of the power system to improve the post disturbance recovery voltages of the generator is necessary. Thus, in this study, hybridized model of STATCOM and SSSC controllers were incorporated on the Nigerian 31-bus power system to improve the system generator damping stability during disturbance. Transient stability of electrical power system with contingency was performed using swing equations technique. Line-Voltage Stability Index (L-VSI) technique was employed to determine the critical load bus for the placement of the controllers. Hybridized model of the STATCOM and SSSC was developed and incorporate into the selected load buses and its impact on stability of the generator oscillation damping was examined. Simulation was done in MATLAB R2023a. The generator damping ratio, total active power losses and total cost of controllers were determined. Results verified the effectiveness of hybridized model of STATCOM and SSSC controllers in improving the stability of power generator oscillation damping.

Keywords: STATCOM, SSSC, Line-Voltage Stability Index, Contingency, Generator Oscillation Damping, Power Loss.

DOI: 10.7176/NCS/15-04

Publication date: February 28th 2025

I. Introduction

Nowadays, the major concern in operating power system is the system's ability to remain stable after it has undergone a disturbance such as a fault, voltage sags or swells, switching transients and sudden increase or decrease in load due to environmental effect and harmonic distortion. These disturbances adversely affect the transmitted power and cause instability in the transmission system [1-5]. Therefore, to meet the high power demand during the disturbance, addition of new stability controller measurement has to be planned [3, 6-9]. One of the most common technical solutions for stability of power system is breaking innovations in power electronic devices which have provided better solution in driving the transition of power systems toward a carbon-free paradigm while maintaining the current standards of quality, efficiency, and resilience [4, 7]

In addition, application of Voltage Source Converter (VSC) based Flexible Alternating Current Transmission System (FACTS) devices such as Static Synchronous Compensators (STATCOM) and Static Synchronous Series Compensator (SSSC) have been widely recognized as most advanced and powerful tools in providing a veritable way to control the transient instability in power system during disturbance [2, 5, 8, 10]. These VSC devices employ self-commutated DC to AC converters, using Gate Turn-Off (GTO) thyristors, which can internally generate capacitive and inductive reactive power for transmission line compensation, without the use of capacitor or reactor banks. They provide unprecedented levels of flexibility and speed of response in comparison with traditional electromechanical devices [11, 12]. The STATCOM provides fast voltage control, reactive power control and power oscillation damping features. The SSSC also improves voltage and transient stability, and effectively improves damping of power oscillations [13-16].

The importance of the VSC has increased due to the increased awareness of energy conservation and quality of supply on the part of the power utility as well as power consumers [17-21]. The FACTS technologies therefore allow for improved power transfer capabilities of the transmission system operation compared to the construction of new transmission lines [22-30].

II. Problem Formulation

This study aimed at improving the stability of Nigerian power system by incorporated hybridized model of STATCOM and SSSC in the system for effective power system monitoring and planning. Thus, the main objective is to optimize the generator load bus with the lowest value of damping oscillation ratio that would enhance the voltage stability of the power system within acceptable voltage limit and minimize the system power loss. The objective is formulated as Equation (1) [4, 23]:

$$OF = Optimize \sum_{\substack{i=1 \\ j \neq 1}}^{N} \left(\Delta P_{GLi} + j \frac{\delta}{\partial t} K_D \right) \tag{1}$$

Subjected to stability constraint: damping ratio limit as in Equation (2):

$$0.03 \leq K_D \leq 0.05 \tag{2}$$

where; P_{GLi} is the equivalent generator power obtained at each load bus, K_D is the generator damping ratio coefficient, δ is the rotor angle, θ is the phase angle,

C. *Transients Stability of Electrical Power System with Contingency*

Here, the generator load power of Nigerian 31-bus system shown in Figure 1 was increased by 90 % (acceptable maximum range of power generator) to compute the power system generator oscillation damping ratio using swing equation. The minimum and maximum damping ratios were set to 0.03 and 0.05. The system generator oscillation damping ratio was monitored for any bus close to the rating limit. The generator voltage, electrical and mechanical power were calculated using Equations (3) to (5) [9, 27]

$$E = V + jX_S \left[\frac{P_g - jQ_g}{V_i^*} \right] \tag{3}$$

$$P_{ei} = E_i^2 Y_{ii} \cos\theta_{ii} + \sum_{\substack{i=1 \\ j \neq 1}}^{N} |E_i||E_j||Y_{ij}| \cos\left(\theta_{ij} - \delta_i + \delta_j\right) \tag{4}$$

$$P_e = P_m - P_a \tag{5}$$

The behavior of the generator is given as in Equation (6) [2, 30]:

$$\frac{H\partial^2 \Delta\delta}{\omega \cdot \partial t^2} = \Delta P_m - \Delta P_e \tag{6}$$

The generator damping ratio was calculated using Equation (7) [13, 29]:

$$\Delta K_{GDi} = \int_{0.03}^{0.05} \left(\Delta P_{GL} - \left| \Delta P_{ei} + \frac{H\partial^2 \Delta\delta}{\omega \partial t^2} \right| \right) \partial t \tag{7}$$

Then, the Line- Voltage Stability index (L-VSI) given in Equation (8) was used to identify the critical buses of the load buses for best location of the STATCOM.SSSC in the Nigerian 31-bus power system.

$$L - VSI = \sum_{i=1}^{N} \left[w_1 \sum \left(\frac{Y_G X_S}{V_i^2} \right) + w_2 \sum \left(\frac{P_{Li} X_S}{V_i^2} + jQ_{Li} \right) + \Delta K_{Di} \right] \tag{8}$$

The load bus with the highest value of L-VSI based on the fitness function was regarded as weak bus for potential placement of generator and STATCOM.SSSC in power system,

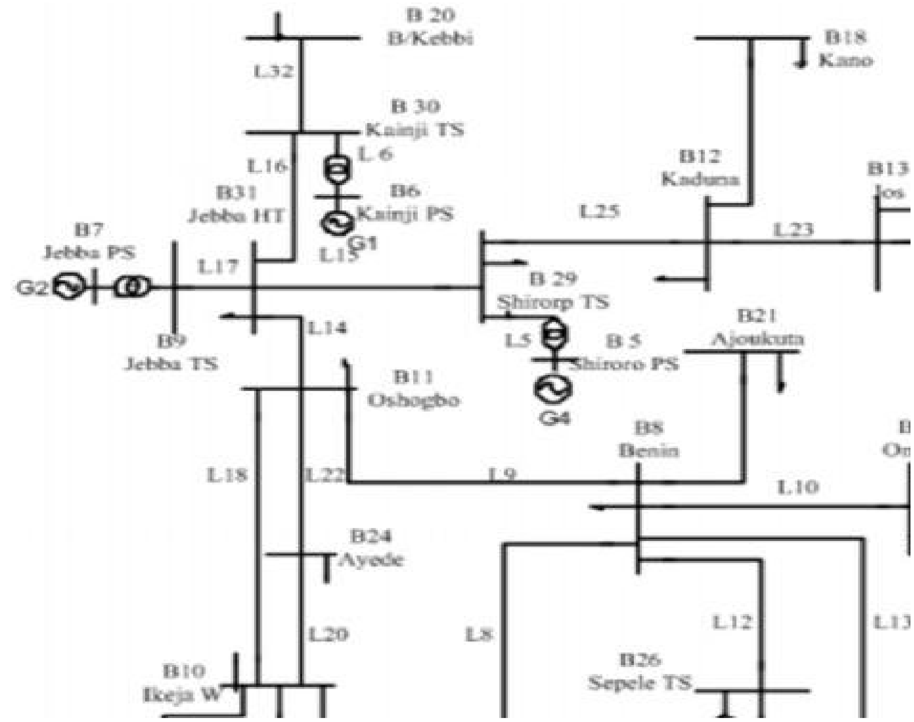

Figure 1: Nigerian 330 kV, 31 –Bus Transmission System [4, 5]

D. *Formulation of Hybridized Model of STATCOM and SSSC controllers*

To improve the system stability and efficiency of generator oscillation damping during disturbance, the STATCOM (shunt FACTS) and SSSC (series FACTS) VSC model was hybridized and used as compensator device to inject reactive power at selected severe buses where the L-VSI are outrageous during contingencies. These controllers were employed due to their ability to increase the power flow transfer capability and maximize the use of existing transmission system [11, 19].

The hybridized STATCOM and SSSC model was developed by shunt connected at the Common Coupling Point (PCC) of the transmission line as generator supporting an inductive reactance with desired voltage magnitude and zero active power generation using voltage magnitude with damping ratio as mismatch calculation termination criteria and their combined model was generated. Then, the transient response of the generator during contingency, the generator excitation voltage and the electrical power with damping was determined for maximum performance.

By considering a typical bus of a transmission power system with two generators represented by an equivalent single line diagram with STATCOM and SSSC shunt connected at bus i as shown in Figure 2. The active and reactive power for uncompensated system is given in Equations (9) and (10) [8, 25]:

$$P_{Unconi} = P_{Di} - \sum_{j=1}^{n} V_i V_{ij} Y_{ij} Cos\left(\theta_{ij} + \delta_j - \delta_i\right) \tag{9}$$

$$Q_{Unconi} = Q_{Di} - \sum_{j=1}^{n} V_i V_{ij} Y_{ij} Sin\left(\theta_{ij} + \delta_j - \delta_i\right) \tag{10}$$

The uncompensated generator excitation voltage and electrical power with damping during contingency is given in Equations (3) and (4).

The shunt connected STATCOM/SSSC voltage source is given in Equation (11):

$$E_{STC/SSSC} = V_{STC}\left(Cos\left(\delta_{STC}\right) + jSin\left(\delta_{STC}\right)\right) + \left(U_{ref} + X_{SSSC} I_{SSSC}\right) \tag{11}$$

The active and reactive power equations of the STATCOM/SSSC are given in Equations (12) and (13):

$$P_{STC/SSSC} = \mathrm{V}_{\mathrm{STC}}^{2} G_{STC} + V_{STC} V_{SSSC} V_{ij}\left(\cos\left(\left(\delta_{STC} + \delta_{SSSC}\right) - \theta_{ij}\right)\right) + V_{SSSC}^{2} B_{SSSC} \tag{12}$$

$$Q_{STC/SSSC} = -\mathrm{V}_{\mathrm{STC}}^{2} G_{STC} + V_{STC}V_{SSSC}V_{ij}\left(\sin\left((\delta_{STC}+\delta_{SSSC})-\theta_{ij}\right)\right) + V_{SSSC}^{2}\frac{B_{SSSC}}{X_L}(\sin 2\alpha) \qquad (13)$$

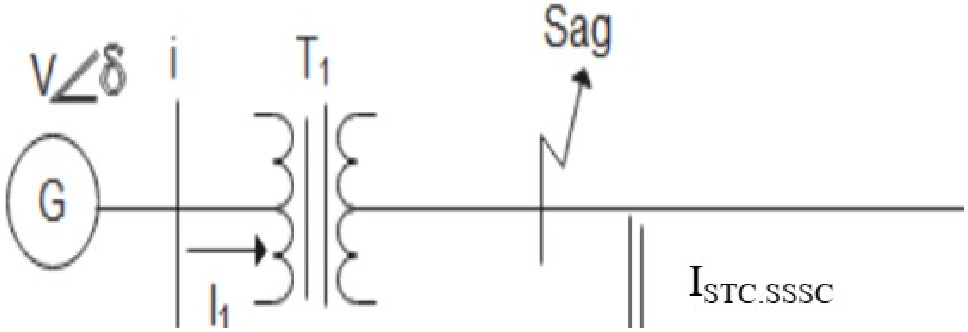

Figure 2: Circuit Diagram of STATCOM /SSSC Compensated Transmission Line

With injection of reactive power via STATCOM/SSSC, the controllers' voltage source with damping state variable is given in Equation (14).

$$V_{STC/SSSC} = \frac{-K_{STC}K_{SSSC}}{K_e}\{L - VSI + \Delta\omega(t-\delta(t))\} \qquad (14)$$

Equation (14) was used to modify the parameters of transmission line with the shunt controller for optimal location.

where; V_{STC} is the STATCOM voltage magnitude, V_{SSSC} is the SSSC voltage magnitude, , U_{ref} is the reference bus voltage, δ_{STC} and δ_{SSSC} are the STATCOM and SSSC phase angle, B_{SSSC} is the susceptance of SSSC, G_{STC} is the STATCOM conductance, θ_{ij} is the firing angle between bus i and j, V_{ij} is the bus voltage between bus i and j, I_1 is the load current, P_{Coni} is the contingency real power for uncompensated system, Q_{Coni} is the contingency reactive power for uncompensated system, X_L is the inductive reactance, K_{STC} is the STATCOM gain constant, K_{SSSC} is the SSSC gain constant, $\partial(t)$ is the damping input signal transmission delay, ω is the generator rotor angle speed, K_e is the exciter gain constant.

In addition, the size of the controllers required for compensation is given in Equation (15):

$$S_{Value} = \frac{Q_{STC} + 1.3Q_{SSSC}}{2\pi \cdot f \cdot V^2} \qquad (15)$$

The active and reactive power injected for compensated transmission system is given in Equations (16) and (17):

$$P_{ij} = P_{Di} + P_{STC/SSSC} - \sum_{j=1}^{n} V_{STC}V_{SSSC}V_{ij}Y_{ij}\cos\left(\theta_{ij} + \delta_{STC} - \delta_{SSSC}\right) \qquad (16)$$

$$Q_{ij} = Q_{Di} - P_{STC/SSSC} - \sum_{j=1}^{n} V_{STCi}V_{SSSC}V_{ij}Y_{ij}Sin\left(\theta_{ij} + \delta_{STC} - \delta_{SSSCi}\right) \qquad (17)$$

The system generator excitation voltage with damping for compensated transmission system is given as Equation (18);

$$\overset{\bullet}{E}{}'_{f} = \frac{K_e}{T_e} = \left(U_{ref} - U_t + V_{STC/SSSC}\right) - \frac{E_f}{T_e} \qquad (18)$$

Thus, the electrical power of the generator with damping was determined using Equations (19):

$$P_{ei} = E_i^2 Y_{ii}\cos\theta_{ii} + \sum_{\substack{i=1 \\ j\neq 1}}^{N} |E_i||E_j||Y_{ij}|\cos\left(\theta_{ij} - \delta_i + \delta_j\right) + P_{STC/SSSC} \qquad (19)$$

where; Y_{ij} is the element of bus admittance matrix between buses i and j, $P_{STC/SSSC}$ is the STATCOM/SSSC active power, E_i and E_j are system source voltage at bus *i* and *j*, f is the EO fitness function

However, the installation of the STATCOM and SSSC controllers in the power system are bound by following operational constraints for effective performance.

i. The power load flow constraints is given in Equations (20) and (21) [4, 24]

$$P_{Gi} - P_{Di} - \sum_{i=1}^{N} |V_i||V_j||Y_{ij}| Cos(\theta_{ij} - \delta_i + \delta_j) = 0 \tag{20}$$

$$Q_{Gi} - Q_{Di} - \sum_{i=1}^{N} |V_i||V_j||Y_{ij}| Sin(\theta_{ij} - \delta_i + \delta_j) = 0 \tag{21}$$

where; P_{Gi} and P_{Di} are the real power generation and demand, Q_{Gi} and Q_{Di} are the reactive power generation and demand, V_i and V_j are the voltage magnitudes at the i^{th} and j^{th} bus, O_{ij} is the angle between buses i and j in the admittance matrix, δ_i and δ_j are the voltage angle at the i^{th} and j^{th} bus, N is the number of buses,.Y_{ij} is the element of bus admittance matrix.

ii. Generation constraints: Real power outputs, reactive power generation limit (size) of the STATCOM and SSSC and their location were restricted by their lower and upper limits as in Equations (22) to (23):

$$P_{Gi}^{Min} \le P_{Gi} \le P_{Gi}^{Max} \qquad i = 1,2,...N_G \tag{22}$$

$$0 \le Q_{STC,SSSC} \le 100 \qquad i = 1,2,.....N_{unit} \tag{23}$$

$$\lambda_i \le N_{bus} \qquad i \in \{1,2,....N_{units}\} \tag{24}$$

Where; N_G is the number of generators, N_{unit} is the number of load buses, P_{Gi}^{Min} and P_{Gi}^{Max} are the generation minimum and maximum power demand respectively, $Q_{STC,SSSC}$ is the STATCOM and SSSC reactive power, λ_i is the location of controller unit.

iii. Load bus constraints: These include the constraints of STATCOM and SSSC voltages at load buses as in Equation (25):

$$V_i^{Min} \le V_i \le V_i^{Max} \qquad i = 1,2.....N_{bus} \tag{25}$$

which is; $0.95 \le V_i \le 1.05$

where; V_i^{Min} and V_i^{Max} are the minimum and maximum controllers voltages limit, respectively,

iv. Stability constraints: damping ratio limit during the contingency as in Equations (2).

E. *Simulation of Incorporation of STATCOM and SSSC for compensation Devices*

Simulation of the STATCOM/SSSC for compensation of the power system with damping was carried out in MATLAB R (2023a) according to the following steps:

Step 1: The system data such as line, generation, and load data were inputted;
Step 2: The system population was initialized and iterations count are set;
Step 3: The L-VSI using the weighted sum of normalized value of the system line loss and generator bus voltage are determined using Equations (8):
Step 4: The hybridized model of STATCOM/SSSC controller are installed at the selected buses based on L-VSI in Step 2;
Step 5: The STATCOM/SSSC control voltage source for compensation system are calculated using Equations (14):
Step 6: The EO fitness value of each search agent are evaluated and the position of the EO current search agent based on L-VSI are updated using Equation (12);
Step 7: The new equilibrium state for each particle (optimal result) are updated based on the current search agent in Step 6, otherwise step 3 are repeated;
Step 8: The generator excitation voltage are updated using Equation (18)
Step 9: The electrical power output of each generator with damping are determined using Equation (18);
Step 10: The size of the controllers required for compensation are calculated using Equation (3.27);
Step 11: The cost of the controllers are determined based on the size in Step 10;
Step 12: The power system stability are checked and stop, otherwise go to step 3.

III. Results and Discussion

In this section, the simulation results of application of hybridized model of STATCOM and SSSC for improvement of generator damping oscillation during contingency on Nigerian 31-bus power system are presented.

Figure 3 analyzed the relationship between the bus voltage and the bus number of the Nigerian 31-bus power system at steady state. It was observed that buses 5 and 21 are buses whose voltage falls with values outside the statutory limit of ±5 % tolerance margin of the voltage criterion range with voltage magnitude of 1.0600 and 0.9430, respectively. These buses are the weak buses and are potential buses for placement of compensator devices in the system.

Furthermore, the line connecting these buses are lines 4-5, 5-6, 5-23, 20-21 and 21-22 with active line losses of 3.90, 1.24, 1.25, -0.24 and 1.25 MW, respectively as shown in Table 1. These buses also have active power loss of 6.39 and 0.24 MW, respectively

In addition, Figure 4 shows the results of the total power losses in the system. The total active and reactive power losses in the system are 341.93 MW and 257.69 MVar.

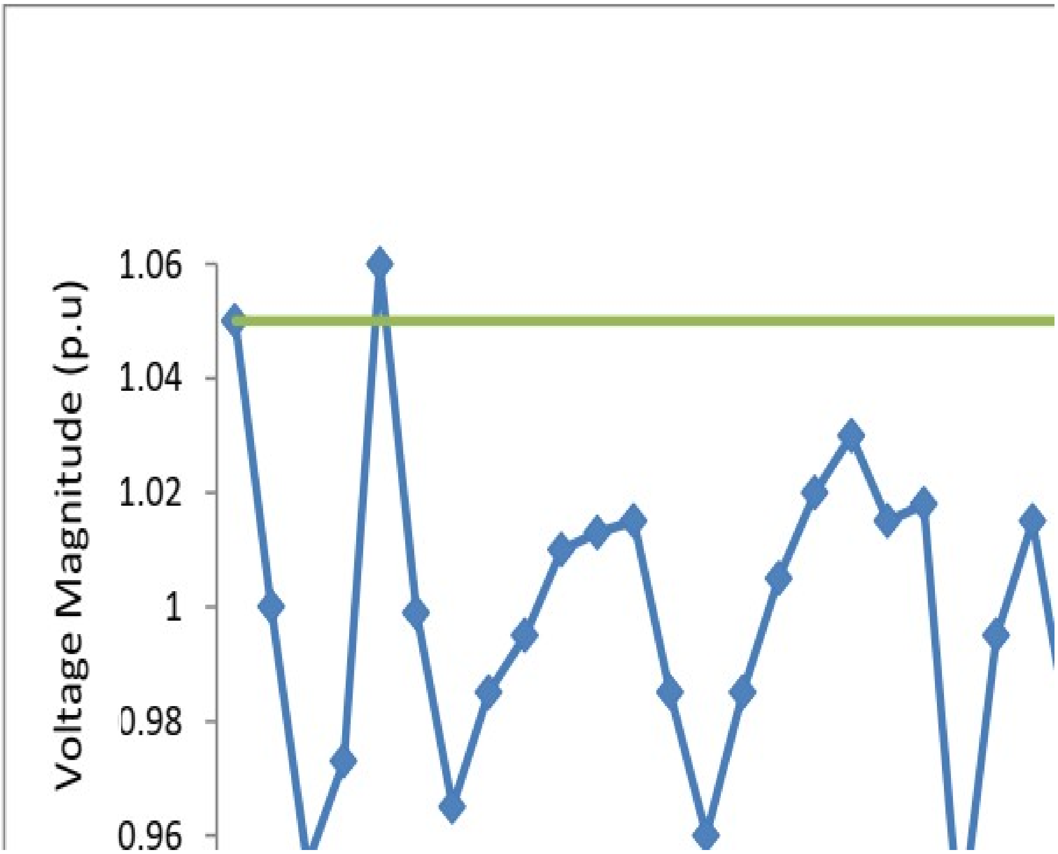

Figure 3: Bus Voltage and Bus Number of Nigerian 31-Bus System at Steady State

Table 1: Line Loss of Selected Buses of Nigerian 31-Bus an Steady State

From Bus	To Bus	Load (MW)	Load (MVar)	Line Loss (MW)	Line Loss (MVAr)
4	5	1.96	0.77	3.90	5.81
5	6	0.06	0.10	1.24	1.24
20	21	0.02	0.77	0.24	0.24
21	22	0.02	0.01	-0.24	-0.24
5	23	0.15	0.26	1.25	1.25

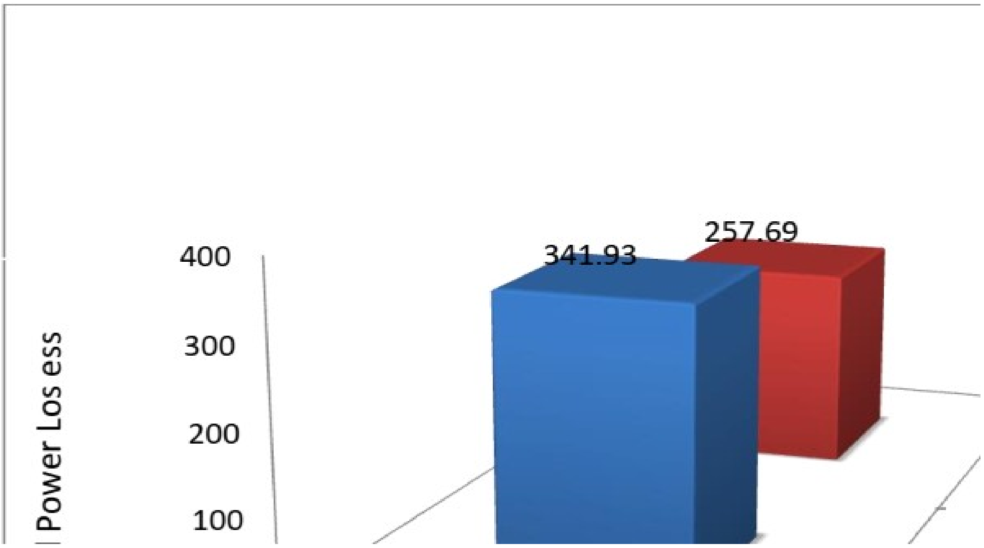

Figure 4: Total Power Losses of Nigerian 31-Bus at Steady State

In order to check the transient stability behavior of the power system, contingency was introduced to the power system by adjusting the generator load power by 90 % one at a time Thus, the results of the damping ratio and the bus number of the power system at contingency are presented in Figure 5. It could be observed that buses 3, 5, 9, 11, 13, 18, 21, 26 and 30 are the buses that fell short of the damping ratio working range with damping ratio value of 0.8, 0.8, 0.7, 0.9, 0.09, 0.08, 0.09, 0.07 and 0.08, respectively, and therefore potential buses for placement of compensator devices.

Figure 6 presents the results of the total power losses in the power system at contingency. The total active and reactive power losses in the system increased to 684.52 MW and 505.68 MVar compared with steady state value and this could result to total voltage collapse of the power system. Therefore, it was observed that with increase in the generator load of the system, the system generator damping ratio were out-off setting range (0.03-0.05) while the voltage magnitude of the power system reduced tremendously compared with steady state value. In addition, the total power losses in the power system increased and this resulted in total voltage instability. This causes unstable transient instability in the power system.

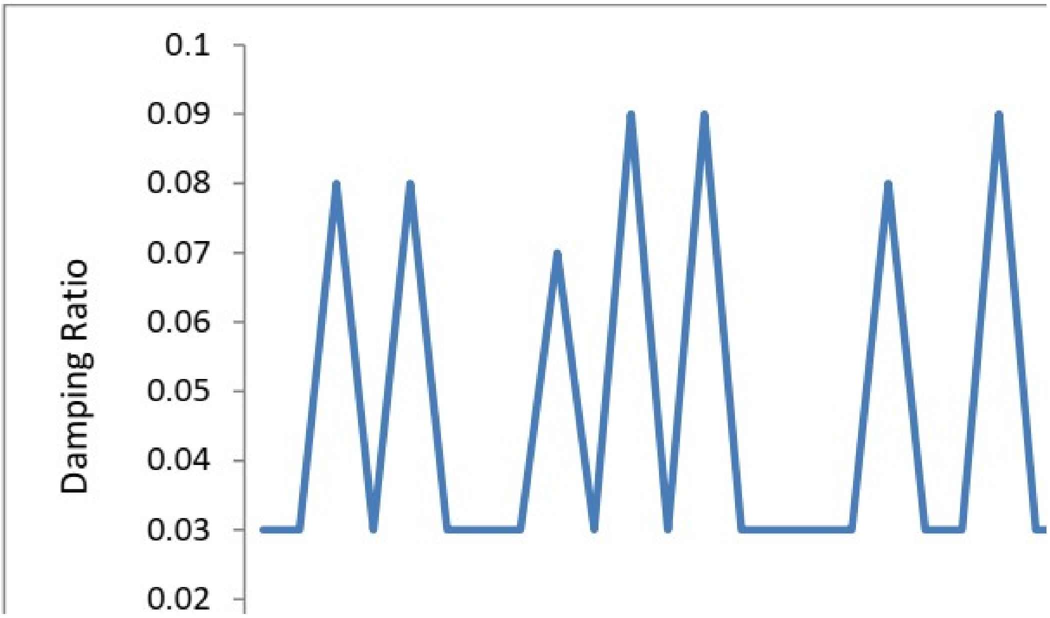

Figure 5: Damping Ratio and Bus Number of Nigerian 31-Bus System at Contingency

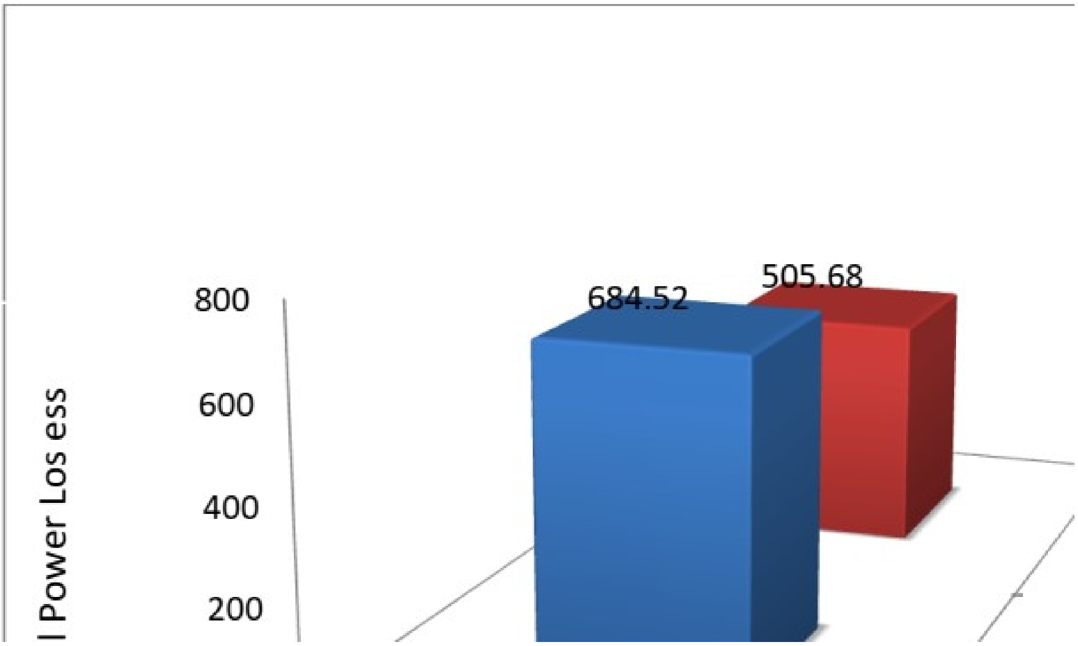

Figure 6: Total Power Losses of Nigerian 31-Bus at Contingency

With the application of optimal L-VSI, optimal buses for placement of VSC in the power system during the contingency were identified. Figure 7 presents the relationship between optimized L-VSI and bus number of Nigerian 31-bus power system at contingency. It was observed that buses 5, 11 and 21 were selected as optimal buses for best location of compensator devices in the power system. These selected optimal buses have L-VSI value of 0.99, 0.97 and 0.99, respectively.

Table 2 presented the load flow results of the selected optimal buses. It could be observed that the selected buses have a voltage magnitude of 0.9503, 0.9506 and 0.9503 p.u. with active line powers of 0.98, 0.66 and 0.04 MW. The total active and reactive power loss in the system reduced to 495.95 MW (27.5 %) and 381.53 MVar (24.6 %) compared with contingency value of 684.52 MW and 505.68 MVar..

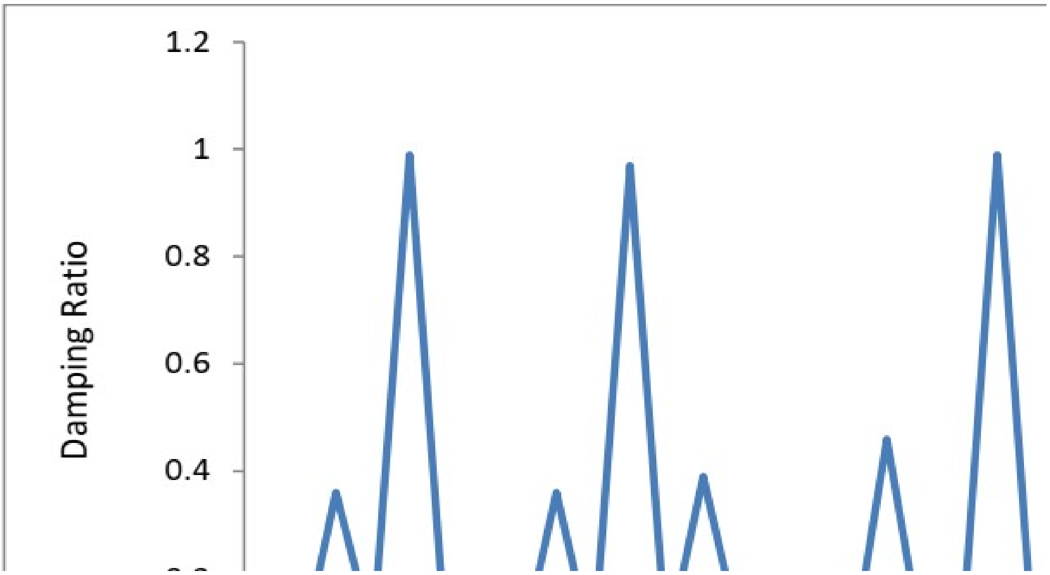

Figure 7: Optimized L-VSI and Bus Number of Nigerian 31-Bus System at Contingency

Table 2: Load Flow Result of Selected Buses of Nigerian 31-Bus at Contingency

Bus No	Voltage Magnitude (p.u)	Load (MW)	Load (MVar)	Line Loss (MW)	Line Loss (MVAr)
5	0.9503	0.98	0.66	9.26	12.95
11	0.9506	0.66	0.88	49.43	-41.64
21	0.9503	0.04	0.36	1.63	-0.70
Total				495.95	381.53

With incorporation of hybridized STATCOM/SSSC controller in Nigerian 31-bus system as presented in Table 3, it was observed that an appropriate STATCOM/SSSC size of 7.78, 7.78 and 7.78 kVar with corresponding cost value of 610 $/kVar each were placed at selected optimal buses 5, 11 and 21, respectively. Furthermore, it was observed that the voltage magnitude of the selected buses at the contingency (3, 5, 9, 11, 13, 18, 21, 26 and 30) with STATCOM/SSSC were improved to 1.0000 p.u each, while the damping ratio of these buses were adjusted to 0.3 each.

Figure 8 shows the comparison of total active power loses of the Nigerian 31-bus system without and with STATCOM/SSSC controller at contingency. The total active power loss in the power system were reduced to 306.16 MW (55.3 %) and 200.22 MVar (60.4 %) compared with contingency value of 684.52 MW and 505.68 MVar.

Table 3: Improvement of Nigerian 31-Bus with STATCOM/SSSC at Contingency

	without STATCOM/SSSC		With STATCOM/SSSC			
Bus No	Voltage Magnitude (p.u)	Damping Ratio	Voltage Magnitude (p.u)	Damping Ratio	Size (kVar)	Unit Cost ($/kVar)
3	0.9050	0.01	1.0000	0.03	---	---
5	**0.9003**	**0.01**	**1.0000**	**0.03**	7.78	610
9	0.9041	0.02	1.0000	0.03	---	----
11	**0.9062**	**0.01**	**1.0000**	**0.03**	7.78	610
13	0.9007	0.01	1.0000	0.03	---	---
18	0.9201	0.02	1.0000	0.03		
21	**0.9101**	**0.01**	**1.0000**	**0.03**	7.78	610
26	0.9401	0.01	1.0000	**0.03**	----	---
30	0.9352	0.01	1.0000	**0.03**	---	---

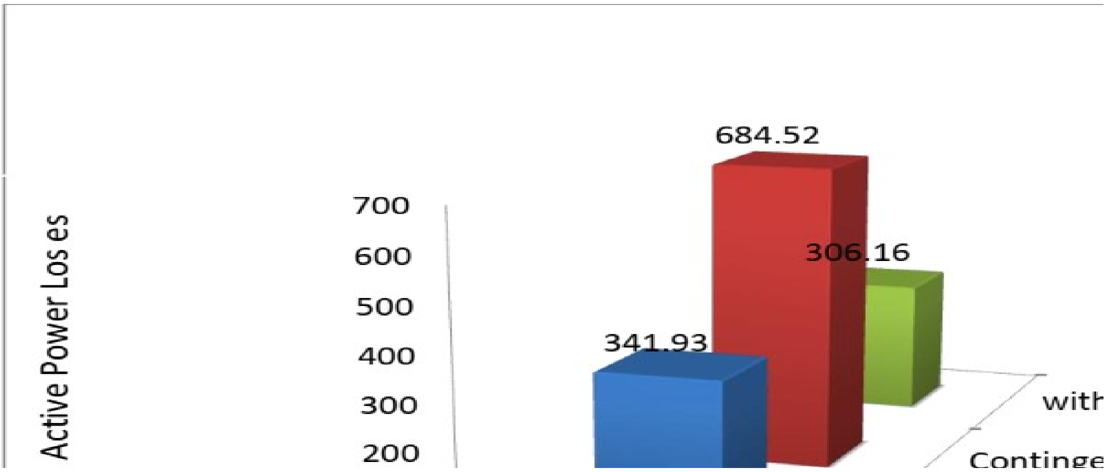

Figure 8: Comparison of Total Active Power Loss of Power System with STATCOM/SSSC

IV. Conclusion

This study has successfully presented the application of hybrid shunt and series FACTS controller for improvement of electric power system generator oscillation damping during contingency. The approach was implemented on Nigerian 31-bus transmission system. It can be concluded from the results that, the hybridized STATCOM/SSSC controller improved the voltage magnitude and damping ratio of the power system to acceptable range. In addition, the total active and reactive power loss in the system reduced to barest minimum compared with contingency without inclusion of STATCOM/SSSC controller. Thus, the results verified the effectiveness of hybridized model of STATCOM and SSSC controllers in improving the stability of power generator oscillation damping.

V. References

[1] Adebayo, I. G. and Sun, Y. (2022). New approaches for the identification of influential and critical nodes in an electric grid. *Archives of Electrical Engineering,* 71(3), pp. 671 –686.

[2] Adebayo, I. G., Jimoh, A. A., Yusuff, A. A. and Sun, Y. (2018). Alternative method for the identification of critical nodes leading to voltage instability in a power system. *African Journal of Science, Technology, Innovation and Development*, 1-2, doi: 10.1080/20421338.2018.1461967

[3] Adejumobi, I. A. (2021). Electricity, man and development: the complexity of the distribution system management in a power network. *FUNAAB Inaugural Lecture Series,* No 64, pp. 21-24.

[4] Adepoju, G. A., Sanusi, M. A. and Tijani, M. A. (2017). Application of SSSC to the 330 kV Nigerian transmission network for voltage control. *Nigerian Journal of Technology*, 36 (4): 1258 – 1264.

[5] Ajenikoko, G. A., Eboda, A. W., Adigun, O., Olayinka, A., Oni, S. O. and Adelowo, L. (2018). Analysis of power sector performance: Nigeria as a case study. *Mathematical Theory and Modeling*, 8 (8): 64-71.

[6] Akwukwaegbu, I. O., Mbachu, C, P, and Ene-Nte, N. P. (2021). Power System Analysis Toolbox (PSAT) circuit design of Nigeria 330 kV 10 generators 28 bus power network for transient stability simulation. *Scientific Research Journal,* 9 (I): 30-38,

[7] Alabi, I.I, Araga, A.I. and Anibasa, A.O. (2017). Optimal location of facts controllers for inter-area oscillation damping in Nigerian national grid using minimum singular value decomposition method. *International Refereed Journal of Scientific Research in Engineering*, 2 (2): 16-23.

[8] Anwar, S.S. and Tanmoy, D. (2014). Voltage stability improvement using STATCOM and SVC. *International Journal of Computer Applications*, 88 (14): 43-47.

[9] Aribi, F. and Nwohu, M.N. (2014). Optimal location of STATCOM in Nigerian 330 kV network using ant-colony optimization meta-heuristic. *Global Journal of Researches in Engineering: Electrical and Electronics Engineering*, 14 (3): 1-7.

[10] Damor, K. G., Patel, D. M., Agrawal, V. and Patel, H. G. (2014). Improving power system transient stability by using Facts devices. *International Journal of Engineering Research and Technology*, 3 (7): 1-5.

[11] Eseosa, O. and Ike, S. (2015). Stability studies of the Nigerian 330 kV integrated power system. *Electrical and Electronic Systems*, 4 (1): 1-12.

[12] Joseph, N. and Dattesh, K. (2018). Comparative survey of STATCOM and SVC integration for power system stability improvement. *International Journal of Creative Research Thoughts,* 6 (1): 2438-2443.

[13] Koundal, G. and Shimi, S. L. (2018). Recent trends on real time simulation of FACTS: a review. *International Conference on Computational and Characterization Techniques in Engineering and Sciences, India.* 1-10.

[14] Martinek, R., Manas, J., Zidek, J. and Bilik, P. (2013). Power quality improvement by Shunt active performance filters emulated by artificial intelligence techniques. *2nd International Conference on Advances in Computer Science and Engineering, India.*

[15] Masood, T., Aggarwal, R. K., Qureshi, S.A. and Khan, R.A. (2010). STATCOM model against SVC control model performance analyses technique by MATLAB. *Renewable Energies and Power Quality*, 1(8): 1314-1321.

[16] More, T. G., Asabe, P. R. and Chawda, S. (2014). Power quality issues and it's mitigation techniques. *Int. Journal of Engineering Research and Applications* 4 (4): 170-177., www.ijera.com,

[17] Noroozian, M. and Taylor, C.W. (2014). Benefits of SVC and STATCOM for electric utility application. *ABB Utilities, FACTS Division*, 7 (21): 1-8.

[18] Okelola, M. O., Amoo, A.L. and Soremekun, R. K. (2019). Power quality events segmentation in a voltage waveform using joint triggering point detection scheme. *FUOYE Journal of Engineering and Technology*, 4 (1): 8-12.

[19] Okwe, G.I., Akwukwaegbu, I.O., Uneze, I.M., Nwaogwugwu, C.N. (2015). Voltage stability improvement of power transmission system in Nigeria using TCSC. *US Open Electrical and Electronics Engineering Journal*, 1 (1): 1-15.

[20] Patil, H. U. (2015). Harmonic resonance in power transmission systems due to the addition of shunt capacitors. *A Master Thesis Submitted to Post Graduate School, Arizona State University*.1.70

[21] Poonam, P. and Siraparapu, S. (2015). The comparative analysis on FACTS devices of SVC, STATCOM and SSSC. *International Journal of Research in Engineering, Science and Technology*, 1 (2): 17-24.

[22] Rao, J. S. and Amarnath, J, (2014). Enhancement of transient stability in a deregulated power system using FACTS devices. *Global Journal of Researches in Engineering: Electrical and Electronics Engineering*, 14 (6): 1-17.

[23] Rashid, H.., AL-Rubayi,, L. and Ibrahim, G. (2020). Enhancement transient stability of power system using UPFC with M-PSO. *Indonesian Journal of Electrical Engineering and Computer Science,* 17 (1): 61-69.

[24] Roche, M. Y., Verolme, H., Agbaegbu, C., Binnington, T., Fischedick, M. and Oladipo, E. O. (2019). Achieving sustainable development goals in Nigeria's power sector: assessment of transition pathways. *Climate Policy,* 1-21, DOI: 10.1080/14693062.2019.1661818.

[25] Sangram, K. M. Balma, Y. O. and Kuwaresh, R. (2012), Improving power system stability using real-coded genetic algorithm based PI controller for STATCOM. *International Journal of Power System Operation and Energy Management*, 1 (12): 73-78

[26] Sanni, S.O. (2014). Assessment of transient stability enhancement capability of unified power flow controller in a multi-machine power system. *A Thesis submitted to the School of Postgraduate Studies, Ahmadu Bello University, Zaria*. 1.30.

[27] Shokri, A., Shareef, H., Mohamed, A. and Shervin, S. (2014). Performance of FACTS devices to improve power quality and application of static synchronous compensator. *Research Journal of Applied Sciences, Engineering and Technology,* 7 (10): 1994-2003.

[28] Siddiqui, A. S. and Deb, T, (2014). Voltage stability improvement using STATCOM and SVC. *International Journal of Computer Applications* 88 (14):43-46.

[29] Sidhartha, P. (2010). Modelling, simulation and optimal tunning of SSSC-based controller in a multi-machine power system. *World journal of Modelling and Simulation*, 6 (8): 110-121.

[30] Xiao, P. (2007). New techniques to improve power quality and evaluate stability in modern all-electric naval ship power systems. *Doctoral Dissertations Submitted to Department of Electrical and Computer Engineering, Scholars' Mine:* 1-104.