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Comparative Effect of Series and Shunt FACTS on the Steady State Improvement of Voltage Profile of the Nigeria 330 kV Transmission System

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Abstract

This paper investigates the comparative effects of static series synchronous compensator (SSSC) and static synchronous compensator (STATCOM) on Nigeria's 48-bus, 330 kV transmission system. The SSSC is connected in series with a transmission line, while the STATCOM is shunt-connected for reactive compensation. The study aims to determine which of the two FACTS devices provides greater improvement to the voltage profile of Nigeria's 48-bus, 330 kV transmission system. The network was modeled using the power system analytical tool (PSAT) and analyzed using MATLAB. Simulation results demonstrate significant improvement across all 48 buses when both SSSC and STATCOM devices are integrated into the network. Specifically, the placement of STATCOM led to a 1.5% increase in voltage profile at the highest bus (Bus 18), from 314.8 kV to 319.5 kV. Conversely, SSSC resulted in a 3.3% increase in bus voltage profile compared to the base case, and a 1.8% increase compared to STATCOM, with Bus 18 reaching 325.3 kV. These findings suggest that for voltage profile improvement in power network design, SSSC FACTS should be prioritized over the shunt counterpart due to its greater impact.

1. Introduction

The power transmission network in Nigeria comprised of several generating and transmission stations over the geopolitical zones with the connecting buses and lines [1, 2]. The 48-bus network employed in this study is based on the operational buses excluding the obsolete ones [3]. The transmission system, also called the grid system, is a high-voltage, interconnected network of transformers and transmission lines [4, 5]. To ensure a consistent and reasonably priced source of electricity, it is desirable to transfer large amounts of electrical power over long distances between locations. For example, the high voltage transmission system can be used to transmit electrical power from generators to load centers [6]. Electrical energy is transported in large quantities from a generating location, like a power plant, to an electrical substation. The interconnecting wires that enable this movement of energy are known as transmission networks [7]. This is different from local wire, which is frequently referred to as electric power distribution, which connects high-voltage substations to customers. The electrical grid, which is used to transmit power, includes the combined transmission and distribution network. Effective long-distance electric power transmission requires high voltages. As a result, losses from strong currents are reduced [8, 9]. FACTS devices are flexible AC transmission system that enables power network to improve voltage profile, power transfer and stability [10, 11]. There are advantages to using FACTS devices in power networks which includes controlling the stability and certain capabilities of the network and preventing voltage collapse, controlling power transfer, enhancing the load-ability of the transmission lines, improving power quality and power factor and voltage profile, improving dynamic stability, and decreasing reactive power losses and as a result increasing active power transfer [12, 13]. The Static Synchronous Compensator (STATCOM) is a reactive compensation device that is parallelly connected to the network and has the ability to produce or absorb reactive power, which can be utilized to regulate specific power system parameters [14]. In order to improve transient stability margins, decrease oscillation in the system, and generate superior dynamic transient characteristics, STATCOM modulates the bus voltage during disturbances. A solid-state voltage source inverter and a transformer connected in series with a transmission line make up a static synchronous series compensator (SSSC), a type of flexible AC transmission system. This device has the ability to add a nearly sinusoidal voltage in parallel with the line [15]. This injected voltage, which is connected in series with the transmission line, can be thought of as an inductive or capacitive reactance. This function may offer adjustable voltage compensation. Additionally, by injecting a sufficiently high series reactive compensatory voltage, SSSC is possible to reverse the power flow [16].

Implementation of the static VAR compensator (SVC) and thyristor-controlled series compensator (TCSC) models into the Newton Raphson power flow equations to improve the available transfer capability (ATC) of a deregulated power network was carried out by [17] using the IEEE 30 bus network system. In the study presented by [18], they compared the performance of the FACTS device based on the total real power loss, real power performance index, real power loss sensitivity with respect to line reactance, power transfer distribution factor (PTDF), line thermal limitation, available transfer capability (ATC) value, and least bus voltage magnitude using IEEE 30 bus test systems. On the other hand, [19] used IEEE-14 bus system to improve ATC with the aid of shunt and series FACTS. They showed that the ideal site for the installation of FACTS devices is established using both real and reactive power loss, sensitivity index, and MATLAB software. [20] stated that reactive power on the power system network can be modified using a static compensator (STATCOM). Therefore, the STATCOM enhances voltage quality and available transfer capability (ATC) in optimal location using voltage stability index with relative voltage change approach. An examination of an intelligent controller tuning for improving transmission line available transfer capability (ATC) using a coordinated control method involving power system stabilizers (PSS) and static synchronous series compensators (SSSC) was presented by [21]. An investigation of the ATC with SSSC and the effects of its control parameter modifications on the ATC enhancement was presented by [22] with the aid of an IEEE 24 bus reliability test system. In [23], they involved unified power flow controller (UPFC) for power transfer improvement on the Nigeria 330 kV transmission system during line failure contingency. They made use of NEPLAN software for the simulation of the network system. They concluded that due to the issues surrounding the power flow of the Nigeria transmission network due to the constant increase in the power demand, utilization of UPFC FACTS for the improvement of ATC in the power system network is best suited for the transmission system.

From the reviewed literatures, it is seen that most researches carried out their work on IEEE reliability test system as well as with limited number of buses. Equally, the researchers could not provide comparison on the effect of series and shunt or unified FACTS on the voltage profile improvement of the transmission system. However, this research is carried out on a real time 48-bus 330 kV transmission system using series and shunt FACTS (SSSC and STATCOM) controllers for improvement of voltage profile of the network system on the five buses having the least voltage profile during power transmission. Equally simulated on power system analytical tool (PSAT) and MATLAB.

2. Methodology

The following materials were used in achieving the work on the application of series shunt FACTS for voltage profile improvement of Nigeria 330 kV transmission system.

i. Data from the National Control Center, Osogbo
ii. PSAT analysis software, version 2.1.10
iii. MATLAB 2023a.

2.1 Method for Determination of the Level of Improvement in Voltage Profile

The flow diagram of Figure 1 describes the procedure for determining the voltage profile of the 330 kV power network of Nigeria transmission system.

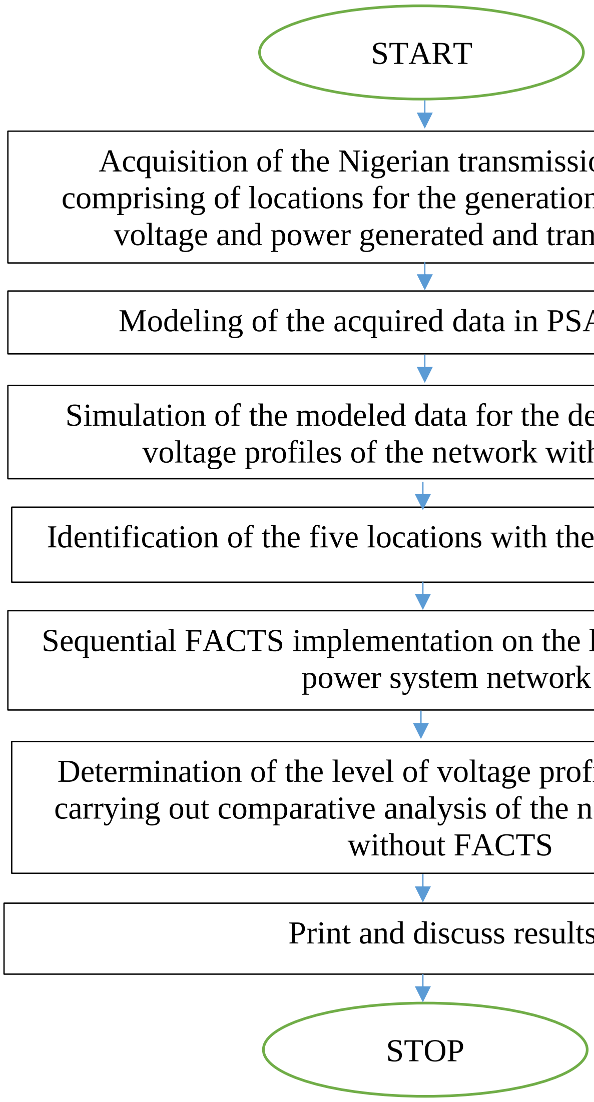

Figure 1: Flow diagram for modeling and determination of voltage profile of the network system

The following steps were utilized in determining the level of voltage profile improvement with the SSSC and STATCOM FACTS devices as stated in [23].

Step 1; subtract each of the voltage of the system without FACTS ($V_{without}$) from the system with FACTS ($V_{Statcom}$ and V_{SSSC} for the voltage outcome for the system with STATCOM and SSSC respectively).

$$V_{outcome-Statcom} = V_{STATCOM} - V_{without} \quad (1)$$

and

$$V_{outcome-SSSC} = V_{SSSC} - V_{without} \quad (2)$$

Step 2; determine the average voltage profile improvement of the power system

$$V_{STATCOM-Avg} = \left(\frac{V_{outcome-Statcom}}{N_{bus}}\right) \quad (3)$$

$$V_{SSSC-Avg} = \left(\frac{V_{outcome-SSSC}}{N_{bus}}\right) \quad (4)$$

Where N_{bus} represents the total number of buses utilized.
Step 3; generate the bar chart for the comparative analysis on the level of voltage improvement.

The following parameters were entered in the power system model in PSAT.

i. Voltage rating of 330 kV was used (the paper centered on Nigeria 330 kV transmission system). Hence, the voltages from the data were divided by 330 kV (voltage rating) to convert from kV to per unit (pu).
ii. For the Nigeria power system model, the power rating used was 100 MW (100 MVar for apparent power).
iii. Since the values of reactance X, resistance R, and susceptance B, entered were in pu, the distance for the transmission lines were zero (source: PSAT manual).

2.2 Network for the Analysis

The 48-bus 330 kV network model with the installation of SSSC and STATCOM is shown in Figures 2 and 3 respectively. The FACTS devices were placed on five least locations for the improvement in voltage profile which were in buses 27, 3, 23, 16 and 31, with the shunt FACTS installed between the buses and the series FACTS installed in transmission line connecting the buses. The power system modeled without FACTS were simulated. Then from the voltage profile obtained from the power flow analysis, the location (buses) with the least voltage values (i.e least five voltages locations) were selected for the FACTS placement.

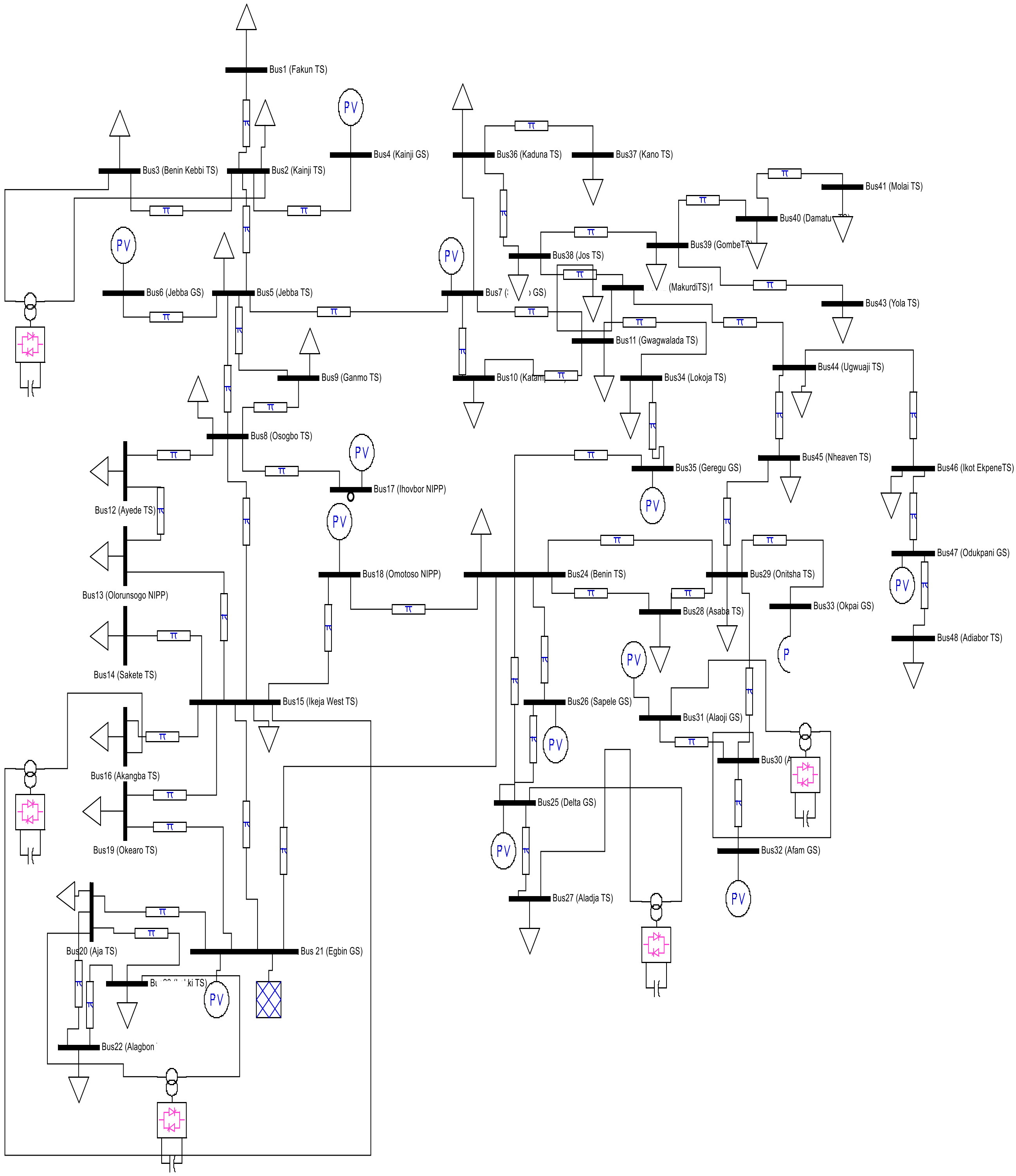

Figure 2: Network model with SSSC

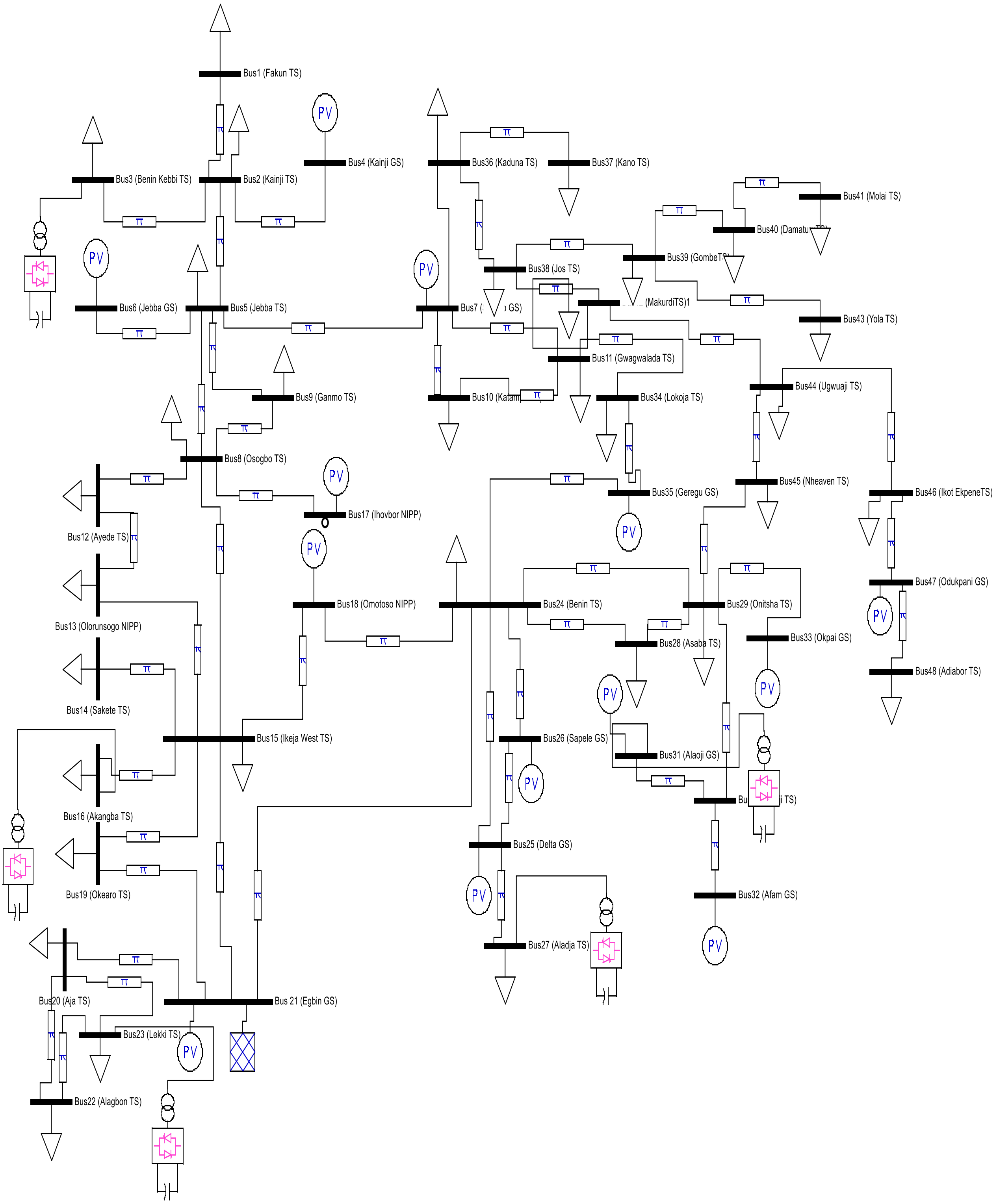

Figure 3: Network model with STATCOM

The bus structure of the 48-bus 330 kV transmission system for the geopolitical zones with SSSC and STATCOM FACTS are shown in the Figure 2 and 3 respectively.

3. Results and Discussion

The results of the voltage profile when the network is operating without FACTS and when SSSC and STATCOM FACTS are placed in the network is shown in Table 1.

Table 1: Voltage profile of the network for with and without FACTS

Bus location	Voltage profile (kV)	STATCOM Voltage profile (kV)	SSSC Voltage profile (kV)
1	313.84	318.55	324.28
2	314.02	318.73	324.47
3	312.10	316.79	322.49
4	313.72	318.42	324.16
5	313.62	318.32	324.05
6	311.65	316.33	322.02
7	311.48	316.15	321.84
8	312.99	317.69	323.41
9	314.84	319.56	325.31
10	312.36	317.05	322.75
11	313.34	318.04	323.77
12	311.90	316.57	322.27
13	314.00	318.72	324.45
14	312.02	316.70	322.40
15	313.02	317.72	323.44
16	313.80	318.50	324.24
17	314.56	319.28	325.03
18	314.84	319.56	325.31
19	313.19	317.89	323.61
20	311.55	316.23	321.92
21	311.60	316.27	321.96
22	312.03	316.71	322.41
23	314.36	319.08	324.82
24	312.02	316.70	322.40
25	314.26	318.97	324.71
26	311.97	316.65	322.35
27	314.72	319.44	325.19
28	312.40	317.09	322.79
29	311.79	316.46	322.16
30	312.00	316.68	322.38
31	313.46	318.17	323.89
32	312.89	317.59	323.30
33	312.41	317.09	322.80
34	314.32	319.04	324.78
35	313.34	318.04	323.77
36	313.20	317.90	323.62
37	314.69	319.39	325.14
38	312.14	316.83	322.53
39	314.03	318.74	324.48
40	314.01	318.73	324.46
41	312.52	317.21	322.92
42	313.27	317.97	323.69
43	311.30	315.97	321.66
44	311.22	315.88	321.57
45	313.12	317.82	323.54
46	314.12	318.83	324.57
47	314.74	319.46	325.21
48	311.52	316.19	321.88

The voltage profile of the power system network without FACTS is shown in Figure 4.

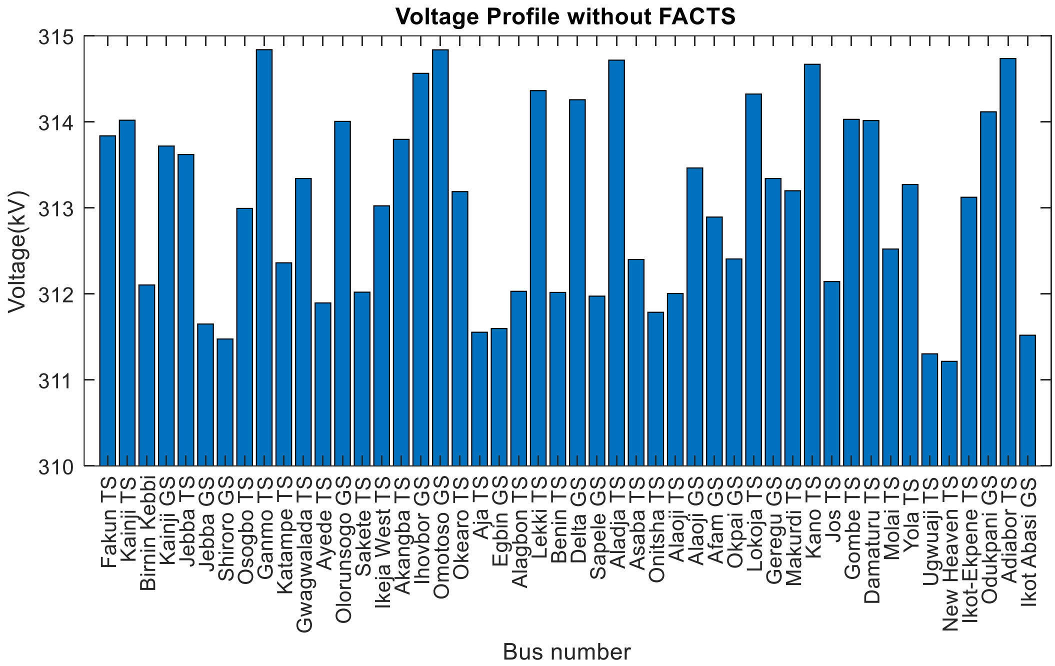

Figure 4: Voltage profile without FACTS

From the voltage of the power system network displayed in Figure 4, the highest voltage of the power flow was at 314.8 kV for Omotoso GS. This implies that the voltage was abnormal due to power congestion on the transmission lines which needs improvement. The voltage profile of the power system network with STATCOM FACTS was shown in Figure 5.

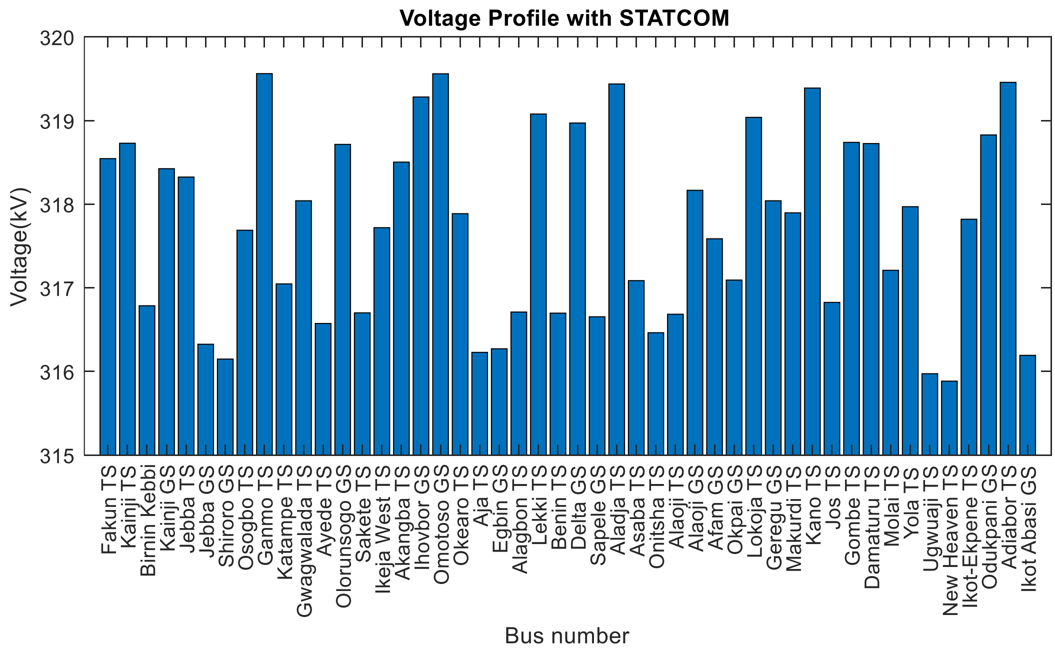

Figure 5: Voltage profile with STATCOM FACTS

The voltage profile improvement with STATCOM shown in Figure 5 has the maximum voltage value of 319.5 kV as compared to 314 kV without FACTS. Though the outcome showed voltage abnormality, there was voltage improvement when compared to the power system without FACTS. The voltage profile of the power system network with SSSC was shown in Figure 6.

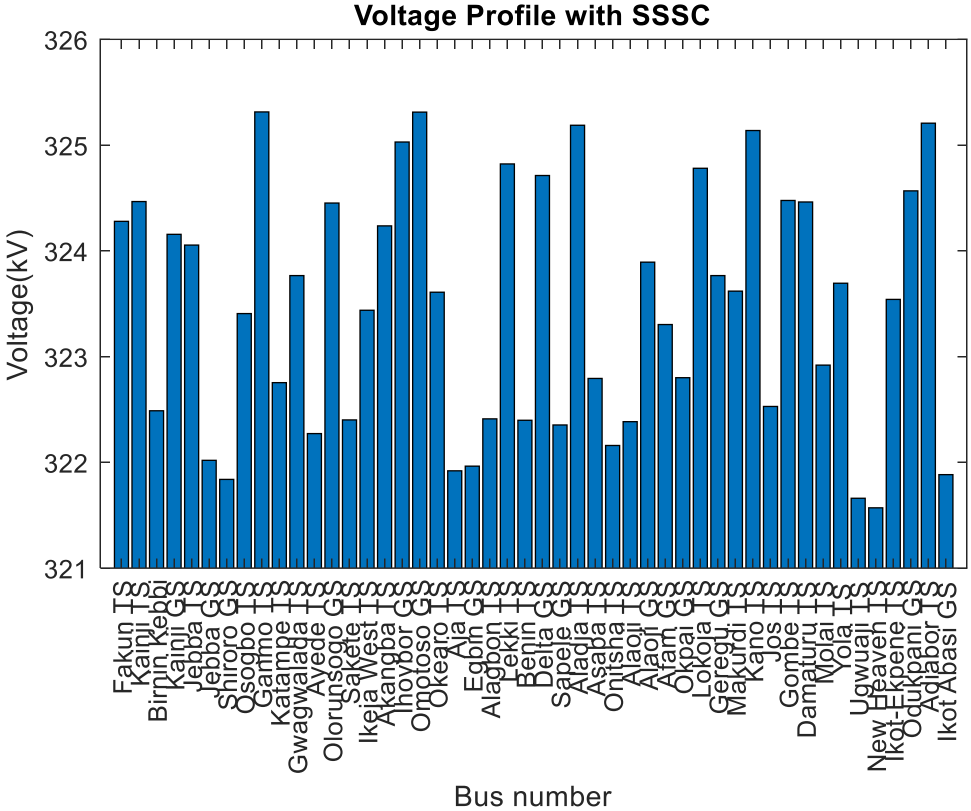

Figure 6: Voltage profile with SSSC FACTS

The voltage profile improvement with SSSC shown in Figure 6 has the maximum voltage value of 325.3 kV. This equally shows that there was voltage improvement when compared to the power system without FACTS and SSSC. The comparative chart showing the effect of the SSSC and STATCOM FACTS on the power network is shown in Figures 7 and 8.

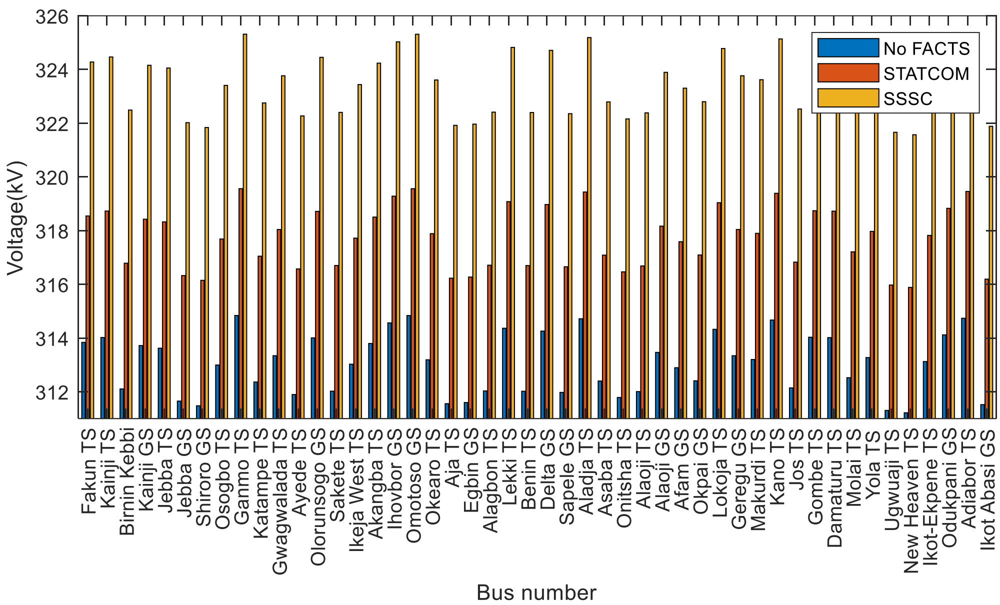

Figure 7: Voltage profile comparison for the 48-bus network

To ensure clarity, the first ten buses from Figure 7 is shown in Figure 8.

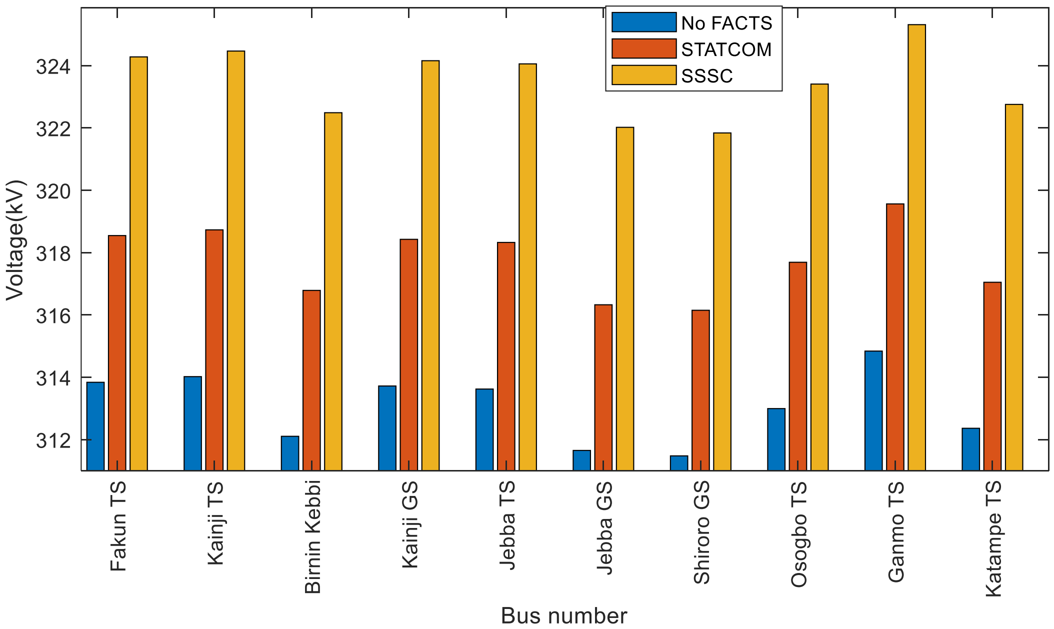

Figure 8: Voltage profile comparison for the first ten buses

From Figures 7 and 8, the voltage profile for the three cases is compared. From Figure 7, the voltage profile with SSSC had the best outcome with the voltage values of 325 kV which approximately is the nominal voltage rating. The bar chart for the level of voltage profile improvement with the FACTS is shown in Figure 9.

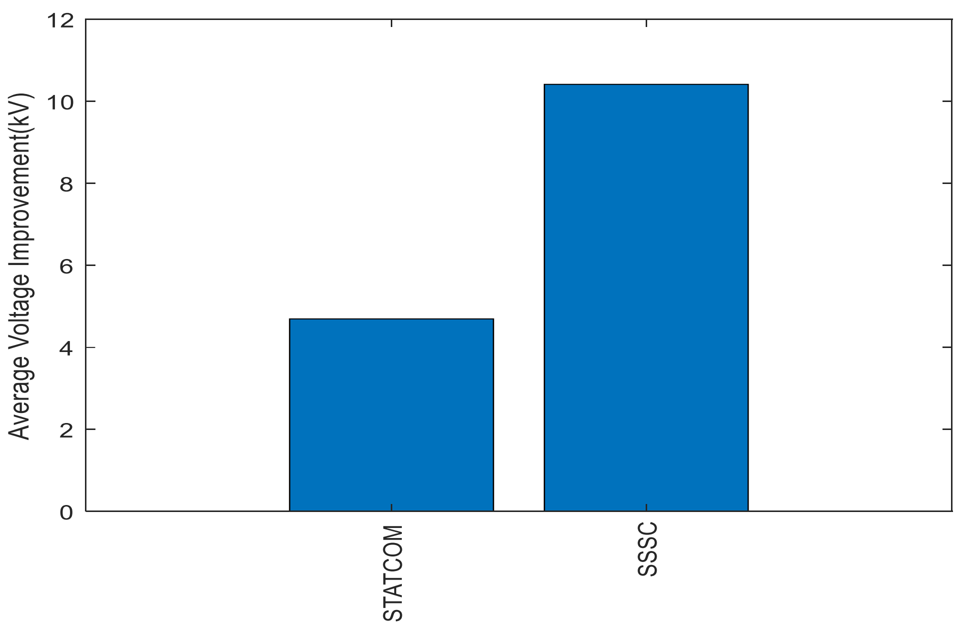

Figure 9: Level of voltage profile improvement with shunt and series FACTS

From Figure 9, it is seen that the average voltage improvement of the network occurs with the SSSC FACTS.

4. Conclusion

From the results of the voltage profile of the buses obtained, it showed an improvement in the entire network bus voltage level from the base case to when STATCOM and SSSC is placed in the network.

Hence, optimally, since the voltage rating generated by SSSC system was close to 330 kV and performed better than STATCOM, the series FACTS should be selected for voltage profile improvement of the network system. The Nigeria power system has over time witness high level of voltage instability (this was proved with the result of the voltage profile of the power system network without FACTS) and the only existing solution has always being installation of power generation stations in locations with low voltage values (results of the power system network without FACTS) with transmissions to the national grid which is costly, complex and dangerous (the locations with low voltage values has been known in Nigeria as the hub of terrorist attacks). Having proved that the utilization of FACTS would improve the voltage profile, it simply suggests that FACTS should be placed in the five locations suggested in this paper as doing so would reduce cost, avert complexities and ensure safety.

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