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Improvement of electricity reliability on the 330 kV Nigeria transmission network with static synchronous compensators

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ABSTRACT

The increasing demand for power has caused distortions in Nigeria's 330 kV transmission network. This is a result of the bulk of the lines being heavily loaded at the moment, which leads to voltage drops and inconsistent electrical delivery. To ensure system reliability, it is therefore crucial to make sure that the system maintains a constant state under specific conditions. This research presents the use of static synchronous compensators (STATCOM) in the Nigerian 330 kV transmission network to reduce power loss and improve the voltage profile. To solve the problem of insufficient voltage and power losses, a three-phase network is simulated using the MATLAB/Simulink software. A three-level, 48- pulse STATCOM was employed to rectify the problem after weak buses were identified through load flow analysis. A 48- pulse converter that handled the STATCOM was used to control harmonic distortions in the system. The outcomes show how crucial the reactive power control mechanism is for regulating the system's harmonics. However, the method was able to achieve real and reactive power losses of 12.5%. The STATCOM's 3-level 48- pulse converter also resulted in a total 4.64% reduction in total harmonic distortion (THD).

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1. INTRODUCTION

Because of several economic, environmental, and regulatory challenges, the majority of power systems nowadays are working under extremely loaded conditions [1]. This also applies to the 330 kV transmission power system network in Nigeria. For electric power utility companies, maintaining voltage stability and minimizing power losses has consequently become increasingly important. Numerous clients, particularly those in the commercial, industrial, and technology sectors, have seen firsthand how crippling blackouts, power outages, and other power supply interruptions can be to their organization [2]. The ability of the power system to maintain an acceptable state of balance following a disturbance and to do so under normal operating conditions is known as power system stability, of which voltage stability is a branch [3]. It becomes extremely difficult to maintain this steady equilibrium in the Nigerian 330 kV transmission network, which balances the active and reactive powers going from generating stations to load centers. The incapacity of a power system to sustain constant voltage across all system nodes following disruption from a particular starting operating condition is known as voltage instability. The imbalance between active and reactive power is the cause of this [4]–[5]. This issue can be resolved by giving the system's weak buses more reactive power support. Voltage collapse may cause system component failures, including customer disruptions and other service availability [6]–[9].

However, system losses in terms of electrical power are crucial to the Nigerian 330 kV transmission network's ability to function. electricity system losses are the result of electricity dissipating within the system and wasted due to internal and external sources [10]. The features and method of operation of the network determine these losses [11]–[14]. Technical and non-technical losses are the two categories into which energy losses fall when delivering power to customers via their transmission and distribution networks [10]. The energy lost in the conductors and machinery used for power distribution, transformation, transmission, and sub transmission is the cause of the technical losses. These technological losses are inherent in the system and can be reduced to an optimum level. Non-technical losses, on the other hand, are brought on by human mistake, energy meter fraud, a variety of readings, and flaws in the energy measurement procedures [9]. Fast response power electronics have been discovered as a result of efforts to solve power system losses in the transmission network [15], [16]. To increase the current gearbox system's useful capacity, these devices can lower gearbox line losses and regulate both active and reactive powers. Flexible alternating current (AC) transmission systems (FACTS), a name for these quick-response power electronics devices, can increase operating voltages and lower transmission line losses [17], [18].

A vector control approach for controlling reactive current using static synchronous compensators (STATCOM) was presented by Schaduer and Mehta [19]. Two STATCOM controller structures were introduced there. One structure employs an inverter for both phase and magnitude control, while the other solely makes use of phase angle control. Nevertheless, not all operational regions of the system can be controlled by a linear output feedback controller due to the later controller construction. To solve this issue, the authors proposed a nonlinear state feedback controller. The control method's intricacy and the system's injection of high frequency noise are its drawbacks. The fundamental idea of STATCOM, its basic functioning, and its functional control system are provided by Gyugi [20]. A three-phase system's reactive and actual power adjustment was modelled. The study, however, focuses on using STATCOM to control the voltage at the midpoint of a long transmission line in order to compensate for reactive power. The plant transfer function is of the minimal phase type, it has been discovered. Padiyar and Kulkarni [21], the design of the voltage controller as well as the simulation and Eigen value analysis of its dynamic behavior were described. To solve this issue, eigen value analysis utilizing a linearized model was used to construct a compensator in cascade with an integral controller. Lechevin and Rajagopalan [22] proposed the construction of a nonlinear controller for STATCOM based on differential algebra theory. By using this approach of controller design, the compensator can be linearized and the capacitor voltage and STATCOM's output reactive power may be directly controlled. This kind of control makes it possible to stabilize the compensation system, which significantly enhances the global system's transient performance. The method's disadvantage is that it causes harmonics to enter the system. An overview of STATCOM converters and control, as well as the new, developing technologies in the system, were presented by Shinde and pulavarthi [23]. In addition to compensating, STATCOM can also be used to increase system stability by implementing different control algorithms and switching strategies. Nikam and Kalkhambkar [24], the multilevel voltage source converter (VSC) architecture and STATCOM were reviewed. Different switching systems, converter topologies, and control algorithms were categorized by the authors. Various multilayer converter strategies are suggested to improve the VSCs performance.

The moth-flame optimization (MFO) algorithm, an effective optimization technique, was proposed by Ebeed *et al.* [25] in order to determine the best location and parameter settings for STATCOM. The transverse direction of a moth flame serves as an inspiration for the MFO optimization technique. In order to minimize power loss, improve voltage stability, and improve voltage profile, STATCOM is integrated into the power system. In order to improve voltage profile, a technology evaluation of STATCOM was conducted in [26]. Its topology, component parts, configuration, and fundamental structure were all described. In the MATLAB/Simulink environment, a STATCOM is simulated to regulate voltage in a nominal π-medium transmission line. The results of the simulation show that STATCOM is a very good voltage regulator, especially when it is used without a drop and precisely tracks the reference voltage. STATCOM control for improving voltage stability at a fixed speed wind farm with unbalanced faults was given by Vimalraj *et al.* [27]. The authors conducted research on a fixed speed wind farm using a STATCOM in conjunction with squirrel cage induction generators that were directly connected to the grid. A STATCOM-based control strategy was presented in [28] for grid-connected wind generating systems serving non-linear loads. Its goals were reactive power adjustment and harmonic reduction. Additionally, the issues with power quality, their effects, and solutions were discussed. In order to maintain power quality at the point of common coupling, the authors employed STATCOM-battery and energy saving system control to remove the harmonic content of the load current. A unique method for improving voltage regulation through automatic control based on a genetic algorithm in STATCOM was given by Ganjefar and Tajali [29]. Testing has been done on the new technique for a step increase in current reference. The STATCOM capacitor voltage was regulated using a linear quadratic regulator (LQR). The selection of matrix coefficients is done using a genetic algorithm. However, it is determined that this method's slow response is its flaw. Voltage profile and power loss analysis were shown by Padhee *et al.* [30] with suitable use of STATCOM; an IEEE 57-bus test system with and without STATCOM was compared. Here, the authors employed STATCOM as a voltage-controlled bus to give the system shunt compensation.

This study describes the application of a shunt FACTS device called a STATCOM to lower transmission line losses and enhance the voltage profile of Nigeria's 330 kV transmission network. In AC transmission networks, the static synchronous compensator, or STATCOM, is a regulating device that can be employed as a source or sink of reactive power. The 330 kV Nigerian transmission network's recognized vulnerable buses are subject to the STATCOM.

2. MATERIALS AND METHOD

Using the Newton-Raphson method in MATLAB and the power system analysis toolbox (PSAT), the power flow analysis is carried out on the Nigerian 330 kV transmission network. This approach was chosen because it produced consistent findings, accelerated convergence, and simplified the calculations. With a total installed capacity of 6500 MW, the Nigerian network consists of seventeen (17) generating stations, fifty-two (52) buses, thirty-five (35) load stations, sixty-six (66) transmission lines, and 8,985.28 km grid transmission lines. Three (3) sectors comprise the electricity system: North, South-East, and South-West. Between Osogbo and Jebba Transmission Station, there is a single double circuit that connects the Northern and South-West. A single line from Osogbo to Benin and a single double circuit line from Ikeja West to Benin connect the South-East and South-West respectively. Figure 1 displays the single line diagram. You can find the bus data and line parameters used in [2].

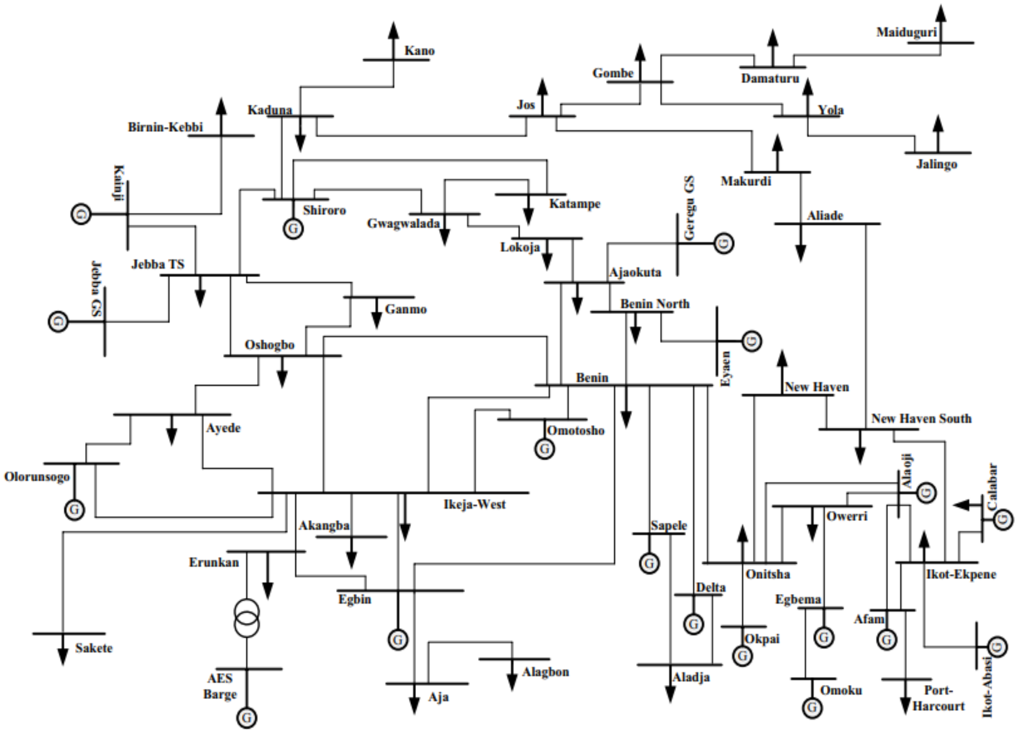


Figure 1. Single line diagram of a 52-bus Nigerian 330 kV transmission network before compensation

Nonetheless, it is specified that values outside of the range of $0.95 \leq |V| \leq 1.05$ pu are not within the standard operating voltage range and must thus be corrected using STATCOM. This is based on a statutory voltage magnitude of ± 5% of the nominal voltage of 1.0 pu. According to the PSAT load flow research, several buses are performing outside of their typical operating range and require compensation in order to improve their efficiency and stabilize the system.

2.1. The operating principles of STATCOM on the 330 kV Nigerian transmission line

Advanced energy storage facilities are well suited for STATCOM, which offers up a host of new applications, including network security and energy markets. By appropriately controlling the inverter voltage $|V_{sh}|\angle\theta_{sh}$ in relation to the AC voltage on the high-voltage side of the STATCOM transformer, STATCOM can produce or absorb reactive power. The reactive power (1) and (2) provide helpful insight into how the reactive power exchange with the AC system is done in a perfect STATCOM, however, when there is no active power loss involved as (1) and (2).

$$Z_{sh} = R_{sh} + jX_{sh} \tag{1}$$

$$y_{sh} = \frac{1}{Z_{sh}} \tag{2}$$

Also, from Figure 2 the net injected current at bus *l* is Figures 2(a) and 2(b):

$$I_l = Y_{ll}^{old} V_l + \sum_{k=1,k\neq l}^{n} Y_{lk}\, V_k + I_{sh} \tag{3}$$

$$Y_{ll}^{old} = \sum_{k=1,k\neq 1}^{n} y_{lk} + y_{l0} \tag{4}$$

where $Y_{ll}{}^{old}$ is the self-admittance of the bus *l* for the original n-bus system without any STATCOM connected. y_{lo} accounts for the shunt capacitances of all transmission lines connected to bus *l*. Secondly,

$$I_{sh} = y_{sh}(V_l - V_{sh}) \tag{5}$$

the net injected current at bus *l* from (3) and (5) with STATCOM is:

$$I_l = \sum_{k=1}^{n+1} Y_{ll}\, V_k \tag{6}$$

$$Y_{il} = Y_{ll}^{old} + y_{sh} \tag{7}$$

where Y_{il} is the new value of self-admittance for the *l*th bus with STATCOM as (8).

$$V_{n+1} = V_{sh} \text{ and } Y_{l(n+1)} = -y_{sh} \tag{8}$$

From Figure 2(b) the net injected current at the nineteen (19) buses equals the current flowing into the transmission system from this bus and is obtained as (9):

$$I_{(n+1)} = -I_{sh} = y_{sh}V_{sh} - y_{sh}V_l = \sum_{k=1}^{n+1} Y_{(n+1)k}\, V_k \tag{9}$$

the net active power injection at any bus *l* in an n-bus system installed with STATCOMs is written from (3) as Without STATCOM connected to bus *l* as (10):

$$P_l = \sum_{k=1}^{n} V_l\, V_k Y_{lk}\, cos\left(\theta_l - \theta_k - \phi_{ylk}\right), l \leq n \tag{10}$$

with STATCOM connected to bus *l* as (11).

$$P_l = \sum_{k=1}^{n} V_l\, V_k Y_{lk}\, cos\left(\theta_l - \theta_k - \phi_{ylk}\right) - V_l V_{sh} y_{sb}\, cos\left(\theta_l - \theta_{sh}\phi_{ysh}\right), l \leq n \tag{11}$$

The reactive power absorbed by STATCOM from the load bus *l* is given as (12):

$$Q_{sh} = [V_{sh} I_{sh}^{*}] \tag{12}$$

where the STATCOM current $I*_{sh}$ is (13) and (14).

$$I_{sh}^{*} = \frac{V_l - V_{sh}}{jX_{sh}} \tag{13}$$

$$Q_{sh} = \left[V_{sh}\left\{\frac{V_l - V_{sh}}{jX_{sh}}\right\}^{*}\right] \tag{14}$$

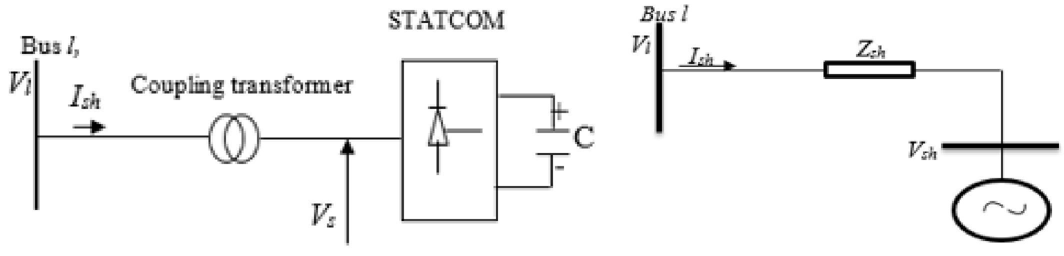
Expanding (12) gives:

$$Q_{sh} = \frac{V_{sh}V_l}{X_{sh}} cos(\theta_{sh} - \theta_l) - \frac{V_{sh}^2}{X_{sh}} \tag{15}$$

again, the reactive power delivered by STATCOM is given as (16):

$$Q = -Q_{sh} = \frac{V_{sh}^2}{X_{sh}} - \frac{V_{sh}V_l}{X_{sh}} cos(\theta_{sh} - \theta_l) \tag{16}$$

where V_{sh} is the STATCOM output voltage, I_{sh} is the current STATCOM draws from the system, X_{sh} represents the leakage reactance of the coupling transformer.



(a) (b)

Figure 2. The net injected current at bus l is (a) a STATCOM connected to any bus *l* of an n-bus power system and (b) the equivalent circuit

3. RESULTS AND DISCUSSION

There are various simulation techniques available for use in load flow investigations, each with unique properties. Common characteristics of these methods include increased speed, precision, and visualisation in comparison to human calculation and result presenting. As a result, PSAT and MATLAB/Simulink were used to simulate the 52-bus system. PSAT software is a feature-rich graphical power flow application that can be used to build, analyses, and alter power flows as well as read solution reports. For both scenarios (before and after correction), the load flow reached a convergence point after seven (7) repetitions. In order to determine the voltage magnitudes, a load flow study was conducted, accounting for a magnitude range of 0.95 pu to 1.05 pu. Buses that exhibit a voltage magnitude that is lower than the lowest statutory range are deemed to have breached the rated limitations and require compensation. There are seventeen (17) generating stations, fifty-two (52) buses, and thirty-five (35) load stations in the simulated Nigerian 330 kV 52-bus network.

The Figure 3 displays the voltage profile results at each bus both before and after compensation. This demonstrates that there are nineteen (19) buses that do not operate inside the 0.95 pu minimal range. Ajah (0.8900 pu), Akangba (0.9009 pu), Aliade (0.6940 pu), New Heaven (0.8041 pu), New Heaven South (0.9048 pu), Makurdi (0.7305 pu), and B/Kebbi (0.7453 pu) are some of the buses that fall under this category. Additionally, Figure 4 displays the network's real and reactive power losses following compensation with STATCOMs.

The enhanced voltage profiles following the use of STATCOM for compensation are displayed in Figure 4. These buses' operating voltages considerably improved and dropped inside the operational range once STATCOM compensation was applied, and the network greatly reduced actual and reactive power losses. This demonstrates that STATCOM can increase the system's stability. The following buses, which had low voltages before, have, according to the results, been sufficiently brought back to operational range by utilising the STATCOM. These are: Benin North (1.0119 pu), Eyaen (0.9515 pu), Alagbon (0.9566 pu), Damaturu (0.9989 pu), Gombe (0.9570 pu), Madugiri (0.9921 pu), Ganmo (1.0204 pu), Jos (1.0502 pu), Yola (0.9540 pu), Sakete (0.9665 pu), Jalingo (0.9506 pu), and Kano (0.9565 pu). These are Ajah (0.9782 pu), Akangba (1.0167 pu), Aliade (0.9613 pu), New Heaven (0.9594 pu), New Heaven South (1.0140 pu), Makurdi (0.9839 pu), and Makurdi (0.9839 pu). Before paying out in the network, the PSAT's specified rate of compensation can be changed. This has to do with adjusting the PSAT's tolerance level to the necessary degree. On the other hand, after applying STATCOM, the overall loss reduction was found to be 12.15% using the equation, and the total harmonic distortion (THD) decreased from 26% to 4.64%.

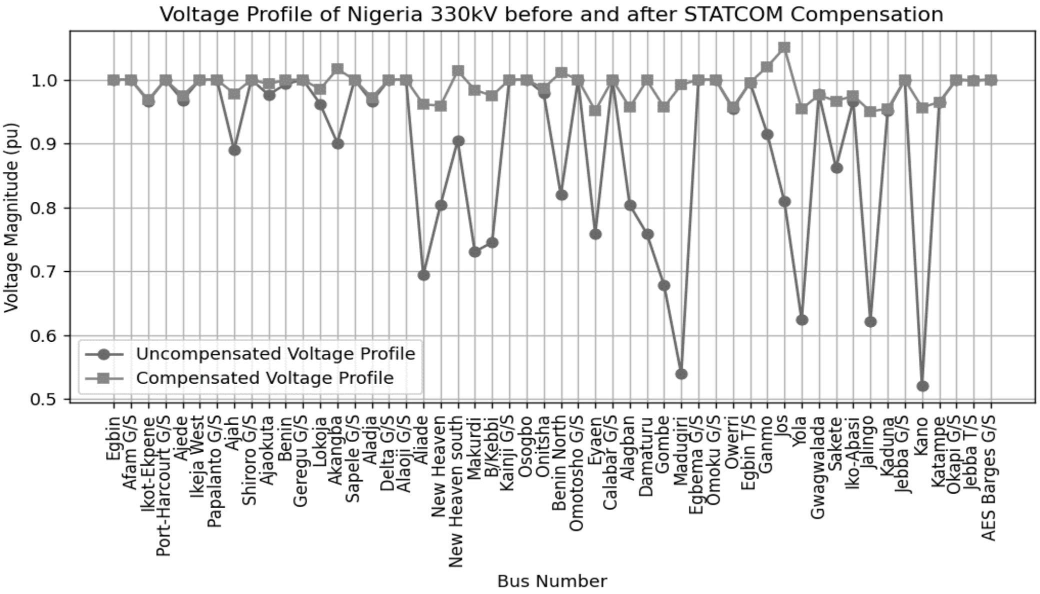


Figure 3. Voltage profile of the network before and after compensation

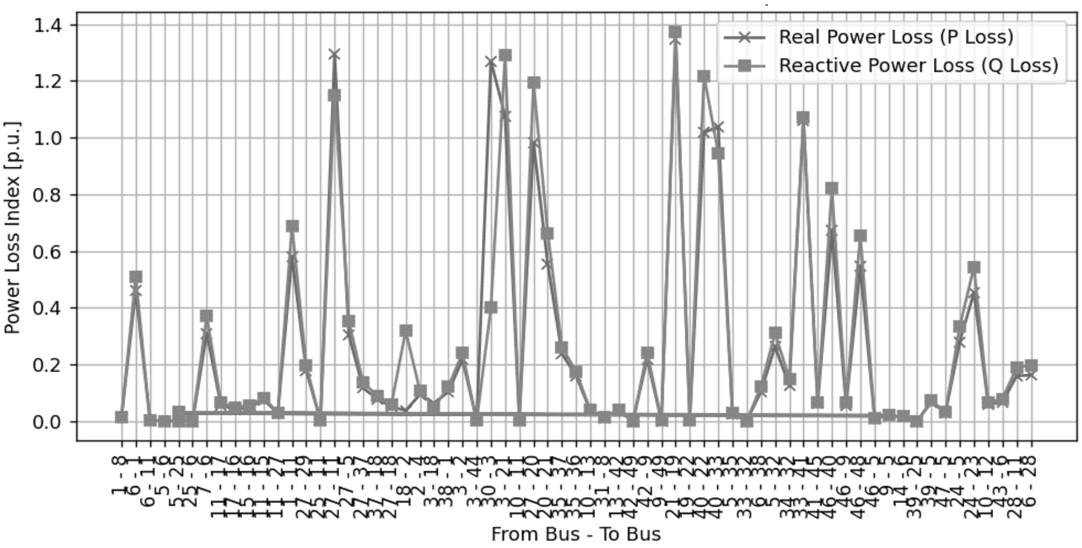


Figure 4. Real and reactive power losses after compensation

4. CONCLUSION

The impact of applying STATCOM to enhance power system performance has been researched and used in the 330 kV, 52-bus Nigerian system to reduce power loss and improve voltage. The three-phase network model was utilized, and MATLAB/Simulink software was employed to conduct the simulation. Once more, a thorough literature assessment of earlier studies on voltage profile enhancement and power loss reduction STATCOM has been completed in order to properly justify the study. To achieve the desired outcomes, a STATCOM controller was used in a full closed loop control architecture. The study's findings, however, indicate that the system's real and reactive power losses were 19.27585 pu and 22.34454 pu, respectively, utilizing prior to compensation. Following compensation as a result of the STATCOM application, the real and reactive power losses decreased to 13.41043 pu and 19.63083 pu, respectively, representing a 12.15% reduction. This demonstrates how the voltage at the system buses affects the quality of the power supply. Furthermore, following the deployment of STATCOM, the THD was 4.64%. In order to ensure power system stability, high performance, and minimal power losses, STATCOM with a 48-pulse rectifier must be applied in the power system. This will also improve the voltage profile.

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