

An Enhanced Intelligent Facts Device for Reduction of Losses on Power Lines

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JERR/2022/v22i917561

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/86904>

Original Research Article

Received 08 March 2022
Accepted 16 May 2022
Published 04 June 2022

ABSTRACT

In this research, an enhanced intelligent FACTS device for reduction of losses on power lines using intelligent Static Synchronous Series Compensator (SSSC) devices for Nigerian 330kv network has been presented. The findings showed total real power losses of 127.9131MW before network compensation, with transmission lines accounting for 125.7MW and producing stations accounting for 2.2131MW. After compensation using Static Synchronous Series Compensator (SSSC), the total Real power losses were reduces to 104.53MW, while the total Reactive losses (MVar) reduced to 26.87MVar. The research concludes that the injection of reactive power by Static Synchronous Series Compensator (SSSC) devices compensates for the drop in voltage, leading to improvement in voltage and reduces power losses for the network.

Keywords: SSSC; losses; 330kv network; FACTS; voltage.

1. INTRODUCTION

Electricity demand in developing countries has risen dramatically as a result of rising population and industrialization, making it critical to run power plants that transfer energy to transmission

and distribution lines as efficiently as possible. The current state of electricity sector losses in Nigeria is concerning. Losses occur regardless of how properly the system is constructed. These losses are inefficient energy dissipated in the system and cannot be accounted for

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because of a difference between energy produced and energy sold to end consumers [1]. Non-technical losses are generally associated with electricity theft arising from commercial, administrative, and non-payment losses. Technical losses are naturally occurring losses associated with heat dissipation in electricity system components such as transmission and distribution lines, transformers, and measurement systems. All of these losses result in high running costs as well as significant revenue losses for utilities, resulting in a high power cost. Researchers have identified system loss as a distinct topic of interest since it represents a significant expense for utilities, customers, and the host country [2].

Furthermore, research indicates several loss estimating methods, however present approaches mostly depend on theoretical calculations and probabilistic data based on simple model data, which are insufficient to provide a correct loss evaluation assessment. As a result, there is still a significant gap between practical information and theoretical information, which is often inaccurate and incomplete, and the reduction of system losses is based on the accuracy of technical losses.

Fundamentally, the goal of this study is to determine the technical losses associated with the current 52 bus test system.

The fundamental issue is calculating the real power loss when transmitting power across a transmission line. The 52 transmission network will be simulated under various aspects of unbalanced faults in order to examine the resulting bus voltages and line currents, which can then be used to evaluate actual power losses, predict the electrical behavior of the system, and propose solutions for reducing losses to improve transmission line efficiency. This study will focus on the usage of SSSC, one of the FACTS devices, in regulating voltage to achieve the most efficient voltage for electric power transmission, using Nigeria's 330kv network as a case study. Flexible Alternating Current Transmission System (FACTS) devices will be used to compensate. The name Flexible Alternating Current Transmission System (FACTS) devices refers to a wide range of high-voltage, large-power electronic converters that can improve the controllability, stability, and power transfer capability of power systems [3]. A FACTS device can be used either individually or in coordination with another FACTS device type

in order to provide control of transmission system parameters of interest, which are essential to the successful operation of the grid [4,5].

FACTS devices improve the transfer capabilities of transmission networks and reduce the possibility of line trips. Additional energy sales due to enhanced transmission capability, decreased wheeling charges due to increased transmission capability, and a delay in the investment of high voltage transmission lines or even new power producing facilities are all benefits attributed to FACTS devices. These devices improve the transfer capabilities of transmission networks and lower the possibility of line trips [6].

2. BENEFITS OF UTILIZING FACTS DEVICES

The advantages of using FACTS devices in electrical transmission systems can be summarized as follows: increased transmission line loading capacity, blackout prevention, increased generation productivity, reduced circulating reactive power, improved system stability limit, voltage flicker reduction, damping of power system oscillations, system stability, security, availability, reliability, and system economic operation [7]. At overvoltage, it reduces the reactive power flow and increases the generation of active power flow, while compensating its shortage [8]

2.1 Static Synchronous Series Compensator (SSSC)

The SSSC is a VSC-based solid-state device that creates a controlled AC voltage and is linked in series to power transmission lines in a power system. By injecting adjustable voltage (VS) in series with the transmission line, SSSC effectively compensates for transmission line impedance. In order to alter the power flow in transmission lines, VS are in quadrature with the line current and simulate an inductive or capacitive reactance [9].

A VSC attached to the secondary side of a coupling transformer controls the variation of VS. A DC voltage source is provided by a capacitor linked to the VSC's DC side. A modest amount of active power is pulled from the line to keep the capacitor charged and to compensate for transformer and VSC losses. IGBT-based inverters are used by VSC. The PWM technique is used to create a sinusoidal waveform from a

DC voltage with a typical chopping frequency of a few kilohertz. Connecting filters on the AC side of the VSC cancel harmonics. A set DC voltage is used in this form of VSC. The modulation index of the PWM modulator is changed to change the converter voltage VC [10].

The magnitude of the series voltage source VS is a configurable quantity. The damper controls this voltage source [11]. The line's steady power flow is controlled by this controller. In principle, SSSC can generate and insert a series voltage, which can be regulated to change the reactance of the transmission line in order to control the power flow of the transmission line or the voltage of the bus, to which SSSC is connected [12].

3. MATERIALS AND METHODS

3.1 Algorithm of N-R Method

The stages for using the N-R approach to solve a power flow problem are as follows:

Except for the slack bus, where V and δ are defined, we assume the bus voltage magnitude and phase angle for other load buses where P and Q are stated. We usually use a flat voltage start, which means we set the expected bus voltage magnitude and phase angle (i.e., the real and imaginary components e and f of the bus voltages) to the slack bus quantities.

We calculate the real and reactive components of power, i.e., P_i and Q_i , for all buses $i = 2, 3, 4, \dots, n$ except the slack bus, by substituting these assumed bus voltages (i.e., e and f) (bus no. 1).

Since P_i and Q_i for any bus i is given, i.e., specified, the error in power will be

$$\begin{aligned} \Delta P_i^r &= P_{i\text{specified}} - P_i^r \dots\dots\dots (1) \\ \Delta Q_i^r &= Q_{i\text{specified}} - Q_i^r \end{aligned}$$

where r is an iteration count.

Here P_i^r and Q_i^r are the power calculated with the latest value of bus voltages at any iteration r.

Then the elements of Jacobian matrix (J_1, J_2, J_3 and J_4) are determined with the latest bus voltages and calculated power equations.

After this the linear set of equation (1) is solved by iterative technique or by the method of elimination (normally by Gaussian elimination method) to determine the voltage correction, i.e.,

Δe_i and Δf_i at any bus i .

This value of voltage correction is used to determine the new estimate of bus voltages as follows:

$$\begin{aligned} e_i^{r+1} &= e_i^r + \Delta e_i^r \dots\dots\dots (2) \\ f_i^{r+1} &= f_i^r + \Delta f_i^r \end{aligned}$$

where r is an iteration count.

Now this new estimate of the bus voltage, i.e. e_i^{r+1} and f_i^{r+1} is for power to re-compute the error in power and thus entire algorithm starting from step 3 as listed above is repeated.

Here in each iteration, the elements of Jacobian are computed as these depend upon the latest voltage estimate and calculated power. The process is continued till the error in power becomes very small.

$$I.E., \Delta P < \epsilon \text{ AND } \Delta Q < \epsilon \quad (3)$$

where ϵ is very small number.

3.2 52 Bus Test System

In the 52 bus test system, load flow analysis is performed. Table 1 Appendix1 shows the output voltage magnitude and voltage angle values from the Newton Raphson method for a 52 bus system. All values are in per unit and angle is given in radian. Fig. 1 depicts a single-line diagram of Nigeria's enhanced 52-bus 330kV transmission network.

3.3 Load Flow Input Data

The load flow data displaying load and generation at the buses is one of the input data for the power flow analysis. The flowchart for Newton-Power Raphson's Flow Solution is shown in Fig. 2.

4. RESULTS AND DISCUSSION

4.1 Results

4.1.1 Result of load flow with and without facts

The first procedure was to run computation of the case study program in software. Then, the simulation was done with and without incorporation of FACT devices.

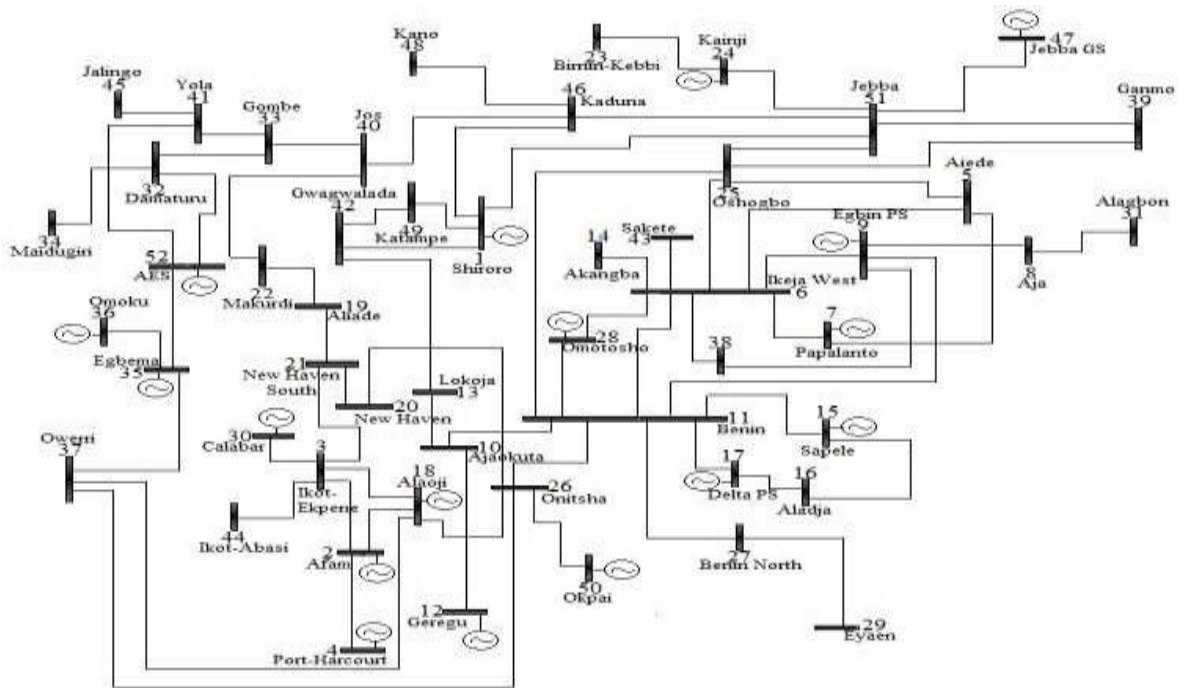


Fig. 1. One-line diagram of the improved 52-bus 330kv Nigerian transmission network

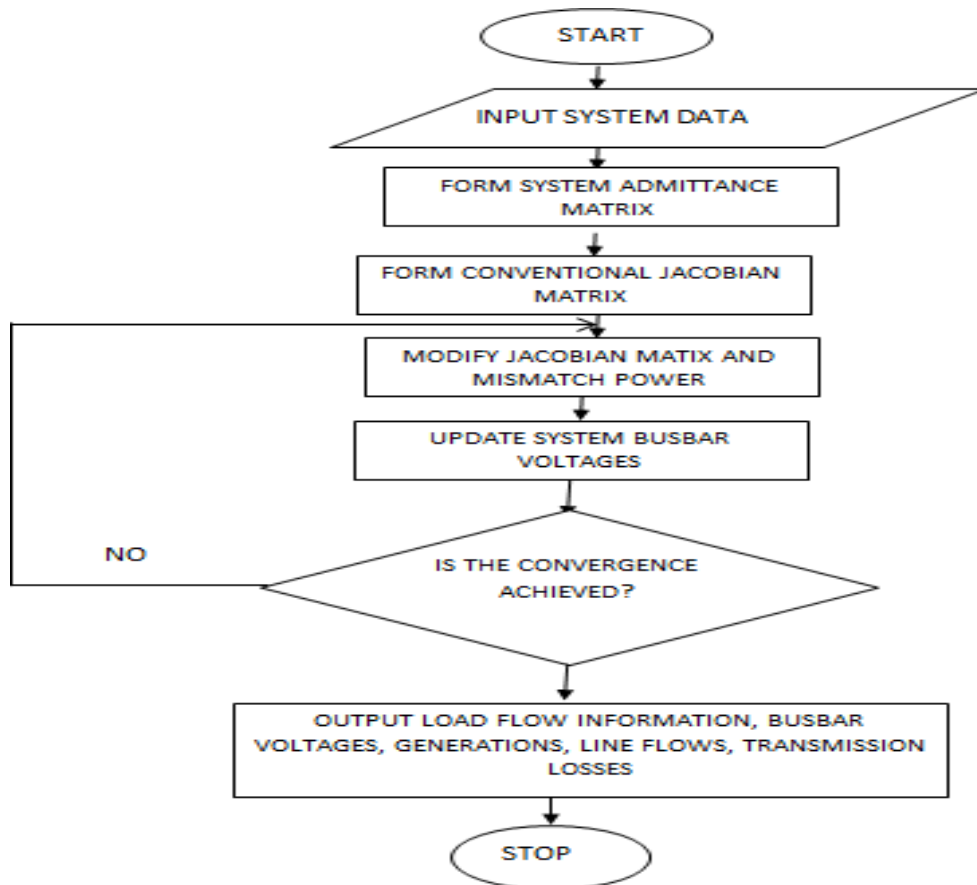


Fig. 2. Flowchart for power flow solution by Newton-Raphson

Table 2 in Appendix 2 shows the Line flow and Losses before compensating with FACTS devices.

From the active power loss for the voltage without SSSC as depicted in Fig. 3, there is a clear indication that the power loss is higher as can be seen in the figure as against the active power loss when an intelligent FACTS device was incorporated as can be seen in fig 4.

The overall Real power losses were reduced to 104.53MW with SSSC compensation, while the total Reactive losses (MVar) were reduced to 26.87MVar.

It can also be clearly deduced that the losses (MW) on buses 8 and 15 in the 52 bus transmission line without compensation is higher than the power losses on the same 8 and 15 buses on the 52 bus power network as seen in Figs. 3 and 4 respectively.

Table 3 in Appendix 3 shows the Line flow and Losses after compensating with FACTS devices.

The active power loss for the voltage with SSSC is shown in Fig. 4.

4.2 Discussion

The acquired results based on the test case (Nigeria 330 kv integrated power system) revealed that the voltage profile and power transfer in the network had significantly improved.

According to the findings, transmission lines account for around 125.7MW of the total real power losses of 127.9131MW before compensation from the network, while generating stations account for 2.2131MW. Furthermore, transmission lines account for 30.75MVar of the total reactive power losses created in the network, while generating stations account for 31.5424MVar.

The overall Real power losses were reduced to 104.53MW with SSSC compensation, while the total Reactive losses (MVar) were reduced to 26.87MVar.

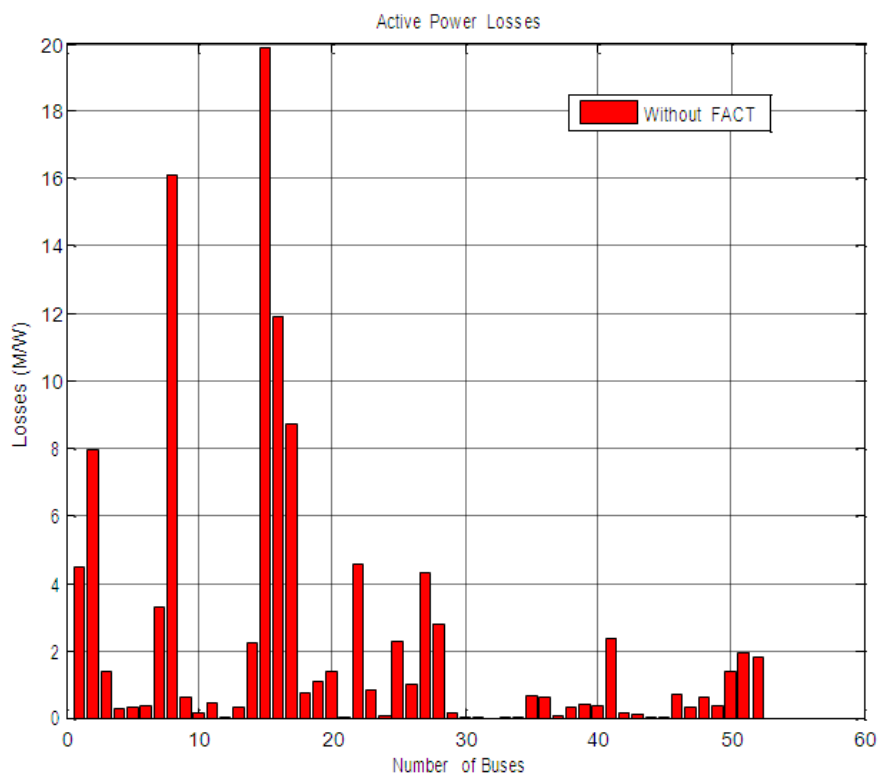


Fig. 3. The active power loss for the voltage without SSSC

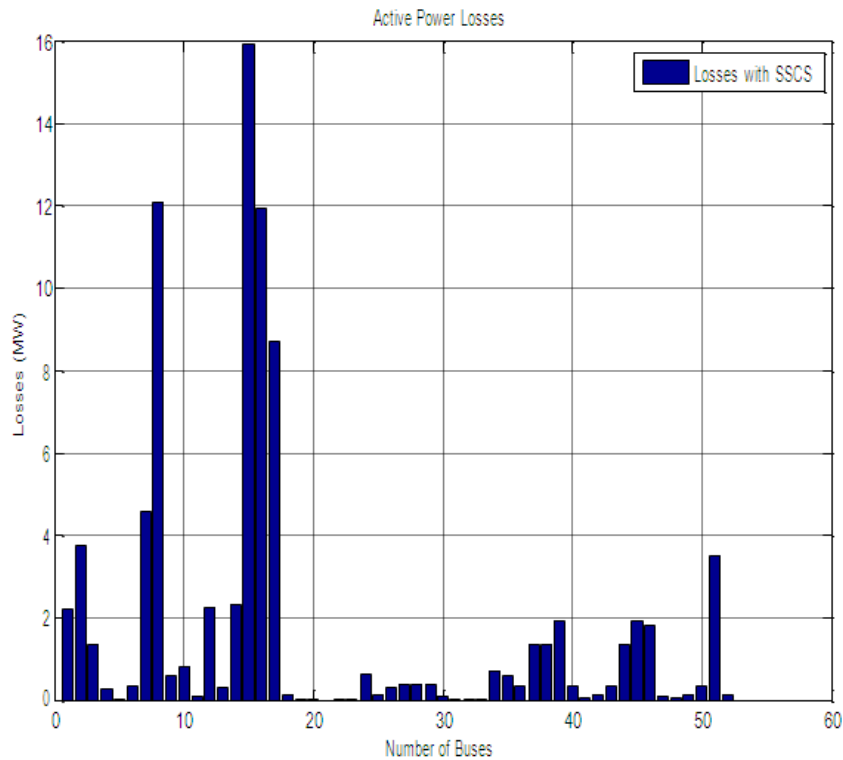


Fig. 4. The active power loss for the voltage with SSSC

5. CONCLUSION

Voltage instability in the Nigerian grid is a severe operating issue for the power provider. The transmission voltage loss in Nigeria's 330kV integrated network is relatively minimal. Though there was a noticeable improvement over the previous situation, some buses and generators with large reactive power values must be balanced using either traditional compensator such as reactors, capacitor banks, and tap altering transformers or FACTS devices.

This study presents an improved intelligent FACTS device for reducing power line losses employing intelligent Static Synchronous Series Compensator (SSSC) devices for the Nigerian 330kV network.

The SSSC device compensates for the voltage drop on weak buses by injecting reactive power, resulting in improved bus voltage magnitudes and a reduction in total active and reactive power losses for the network.

DISCLAIMER

The products used for this research are commonly and predominantly used products in

our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Ogbuefi UC, Madueme TC. A Power Flow Analysis of the Nigerian 330kV electric power system. IOSR Journal of Electrical and Electronics Engineering (iosr-jeee). 2015;10:46–57.
2. Sakthivel S, Mary D, Vetrivel R, Senthamarai KV. Optimal Location of SVC for Voltage Stability Enhancement under contingency condition through PSO algorithm. International Journal of Computer Applications. 2012;20(1).
3. Singh B, Verma KS. Introduction to FACTS Controllers: A Technological

- Literature Survey International Journal of Automation and Power Engineering. 2012;1(9). Available:www.ijape.org December 15
4. Adetokun BB, Muriithi CM. Application and control of flexible alternating current transmission system devices for voltage stability enhancement of renewable-integrated power grid: A comprehensive review. *Heliyon*. 2021;7(3):e06461.
 5. Shehata AA, Korovkin NV, Tolba MA, Tulsy VN. Efficient Utilization of the Power Grid using FACTS devices based on a new Metaheuristic Optimizer. In 2021 3rd international youth conference on radio electronics, electrical and power engineering (REEPE). 2021;1-7. IEEE.
 6. Kumar VK, Dubey S. Generators and Loads Contribution Factors Based Congestion management in electricity markets. *International Journal of Recent Trends in Engineering*. 2013;2(6).
 7. Venkateswarlu K, Babu KC. Analysis and Enhancement of Transient Stability using Shunt Controlled FACTS Controller, *International Journal of Engineering Sciences*; 2011.
 8. Vasudevan K. Maintaining Voltage Stability by Optimal Locating and Sizing by Combined Evolutionary Algorithm, *International Journal of Computer Applications*. 2013;84(12):39-45.
 9. Darly SS, Vanaja BR. Modeling, Simulation and Fault Diagnosis of IPFC using P.E.M.F.C for High Power Applications, *Journal of Electrical Engineering Technology*. 2013;8(4):760-765.
 10. Acha EC, Fuerte-Esquivel CR, Ambriz-Perez H. *FACTS: Modeling and Simulation in Power Networks*, London, U.K.: Wiley; 2011.
 11. Adepoju GA, Sanusi MA, Tijani MA. Department of Electrical /Electronic Engineering. Ladoke Akintola University. *Nigerian Journal of Technology (Nijotech)*. 2017;36(4):1258-1264.
 12. Bashirov M, Khismatullin A, Sirotina E. *Lecture Notes Electrical Engineering*. 2020;613-621.

LIST OF APPENDICES

Appendix 1

Table 1. Bus voltages and angles of the integrated 52 network using N-R algorithm

| Bus Number | Bus Name | PU Voltages | Angles (degrees) |
|------------|-----------------|-------------|------------------|
| 1 | Shiroro | 1.040 | -36.32 |
| 2 | Afam | 1.036 | -24.45 |
| 3 | Ikot-Ekpene | 1.040 | -18.23 |
| 4 | Port-Harcourt | 1.023 | -13.34 |
| 5 | Aiyede | 1.036 | -15.23 |
| 6 | Ikeja west | 1.002 | -23.41 |
| 7 | Papalanto | 1.041 | -16.23 |
| 8 | Aja | 1.022 | -23.42 |
| 9 | Egbin PS | 1.038 | -33.45 |
| 10 | Ajaokuta | 0.989 | -9.15 |
| 11 | Benin | 1.030 | -11.32 |
| 12 | Geregu | 1.042 | -10.24 |
| 13 | Lokoja | 1.025 | -14.32 |
| 14 | Akangba | 1.019 | 21.23 |
| 15 | Sapele | 1.027 | -21.12 |
| 16 | Aladja | 1.001 | -14.23 |
| 17 | Delta PS | 1.047 | -11.34 |
| 18 | Alaoji | 1.037 | -9.39 |
| 19 | Aliade | 1.039 | -23.43 |
| 20 | New Haven | 1.055 | -13.58 |
| 21 | New Haven South | 0.965 | -19.31 |
| 22 | Makurdi | 0.912 | -16.62 |
| 23 | B-kebbi | 0.988 | 9.46 |
| 24 | Kainji | 1.014 | -11.45 |
| 25 | Oshogbo | 1.046 | -18.34 |
| 26 | Onitsha | 1.022 | -29.23 |
| 27 | Benin North | 1.043 | -23.16 |
| 28 | Omotosho | 1.052 | -18.23 |
| 29 | Eyaen | 1.024 | -9.34 |
| 30 | Calabar | 1.036 | -7.34 |
| 31 | Alagbon | 0.995 | -10.56 |
| 32 | Damaturu | 0.924 | -12.32 |
| 33 | Gombe | 0.941 | -22.15 |
| 34 | Maiduguri | 0.943 | -6.34 |
| 35 | Egbema | 1.033 | -12.10 |
| 36 | Omoku | 1.045 | -26.21 |
| 37 | Owerri | 1.023 | -6.21 |
| 38 | Erunkan | 0.982 | -14.23 |
| 39 | Ganmo | 0.984 | -23.03 |
| 40 | Jos | 0.937 | -10.41 |
| 41 | Yola | 0.921 | -16.21 |
| 42 | Gwagwalada | 0.998 | -23.21 |
| 43 | Sakete | 0.986 | -9.45 |
| 44 | Ikot-Abasi | 1.024 | -11.45 |
| 45 | Jalingo | 0.922 | -6.11 |
| 46 | Kaduna | 0.992 | -10.23 |
| 47 | Jebba GS | 1.023 | -11.22 |
| 48 | Kano | 0.994 | -11.25 |

| Bus Number | Bus Name | PU Voltages | Angles (degrees) |
|------------|----------|-------------|------------------|
| 49 | Katampe | 1.001 | -9.28 |
| 50 | Okpai | 1.034 | -23.15 |
| 51 | Jebba | 1.045 | -17.37 |
| 52 | AES | 1.023 | -32.11 |

Appendix 2

Table 2. Line flow and losses before compensation

| From bus | To Bus | From Bus P | Injection Q | To Bus P | Injection Q | Loss P (MW) | Loss Q (MW) |
|----------|--------|------------|-------------|----------|-------------|-------------|-------------|
| 49 | 1 | 102.0 | 75 | -100 | -84.1 | 1.31 | 4.44 |
| 14 | 6 | 97.77 | -4.64 | -94.9 | 4.46 | 2.79 | 7.97 |
| 2 | 18 | 60.21 | -8.18 | -59.7 | 5.89 | 0.42 | 1.38 |
| 2 | 3 | 13.80 | -4.43 | -13.6 | 2.24 | 0.13 | 0.28 |
| 2 | 4 | 14.16 | -5.09 | -14.0 | 2.08 | 0.09 | 0.33 |
| 16 | 15 | -17.8 | -1.71 | 17.8 | -0.62 | 0.06 | 0.34 |
| 5 | 25 | -42.5 | -6.56 | 43.1 | 5.22 | 0.64 | 3.29 |
| 5 | 6 | 178 | 19.8 | -174 | -9.12 | 3.15 | 16.1 |
| 5 | 7 | 17.17 | -9.23 | -17.0 | 5.58 | 0.13 | 0.60 |
| 8 | 9 | 12.90 | 2.07 | -12.8 | -3.99 | 0.04 | 0.16 |
| 8 | 31 | 2.55 | -15.8 | -2.45 | 8.64 | 0.10 | 0.47 |
| 10 | 11 | 2.32 | -1.9 | -2.31 | -1.93 | 0.03 | 0.01 |
| 10 | 12 | -10.3 | 22.3 | 10.4 | -23.1 | 0.87 | 0.29 |
| 10 | 13 | -48.8 | 4.89 | 49.5 | -4.91 | 0.68 | 2.20 |
| 16 | 17 | 148.9 | 33.7 | -145 | -23.9 | 3.90 | 19.9 |
| 18 | 26 | 79.25 | -0.87 | -76.6 | 7.08 | 2.63 | 11.9 |
| 18 | 3 | 93.34 | 3.94 | -91.4 | 1.77 | 1.92 | 8.73 |
| 18 | 37 | 33.77 | -18.1 | -33.5 | 13.6 | 0.23 | 0.75 |
| 19 | 21 | 13.96 | 2.44 | -13.9 | -1.35 | 0 | 1.09 |
| 19 | 22 | 17.87 | 1.19 | -17.8 | 0.18 | 0 | 1.37 |
| 23 | 24 | 0.67 | -6.24 | -0.66 | 5.07 | 0.01 | 0.02 |
| 11 | 6 | -77.9 | -12.1 | 78.8 | 15.0 | 0.89 | 4.56 |
| 11 | 15 | -17.6 | -20.0 | 17.7 | 17.6 | 0.18 | 0.85 |
| 11 | 17 | -9.93 | -4.39 | 9.95 | 2.68 | 0.02 | 0.09 |
| 11 | 25 | -0.49 | 60.3 | 1.18 | -64.0 | 0.69 | 2.27 |
| 11 | 26 | -33.4 | 8.82 | 33.6 | -10.0 | 0.21 | 0.96 |
| 11 | 27 | -48.4 | 9.17 | 49.4 | -9.77 | 0.95 | 4.32 |
| 11 | 9 | -68.8 | -9.60 | 69.7 | 10.9 | 0.87 | 2.80 |
| 11 | 28 | 4.63 | 1.39 | -4.53 | -1.23 | 0.10 | 0.16 |
| 27 | 29 | 1.23 | 0.63 | -1.22 | -0.62 | 0.06 | 0.01 |
| 30 | 3 | 1.08 | 0.39 | -1.08 | -0.38 | 0 | 0.01 |
| 32 | 33 | -1.08 | -0.39 | 1.08 | 0.40 | 0.01 | 0 |
| 32 | 34 | 9.65 | 3.11 | -9.64 | -3.10 | 0.01 | 0.02 |
| 35 | 37 | 3.34 | 1.00 | -3.32 | -1.81 | 0.02 | 0.03 |
| 35 | 36 | 7.07 | 1.71 | -7.07 | -1.09 | 0 | 0.63 |
| 9 | 6 | 6.79 | 1.65 | -6.79 | -1.05 | 0 | 0.60 |
| 10 | 38 | -10.5 | -1.55 | 10.5 | 1.61 | -0 | 0.06 |
| 38 | 6 | -10.5 | -1.61 | 10.7 | 1.93 | 0.20 | 0.31 |
| 39 | 25 | -20.0 | -2.43 | 20.3 | 2.83 | 0.26 | 0.40 |
| 39 | 51 | -24.9 | -5.13 | 25.1 | 5.51 | 0.27 | 0.38 |
| 33 | 40 | 60.09 | 13.3 | -60.0 | -10.6 | 0.00 | 2.36 |
| 44 | 41 | 7.56 | 4.63 | -7.45 | -4.46 | 0.11 | 0.16 |
| 42 | 49 | 3.85 | 2.66 | -3.77 | -2.55 | 0.07 | 0.12 |
| 42 | 13 | -2.03 | -0.35 | 2.05 | 0.39 | 0.02 | 0.04 |

| From bus | To Bus | From Bus P | Injection Q | To Bus P | Injection Q | Loss P (MW) | Loss Q (MW) |
|----------|--------|------------|-------------|----------|-------------|-------------|-------------|
| 42 | 1 | 3.81 | 1.91 | -3.80 | -1.90 | 0.08 | 0.01 |
| 6 | 5 | 7.46 | 3.79 | -7.46 | -3.10 | 0 | 0.70 |
| 6 | 28 | -7.46 | -3.79 | 7.50 | 3.55 | 0.03 | 0.32 |
| 6 | 7 | -13.5 | -6.55 | 13.6 | 6.53 | 0.10 | 0.59 |
| 6 | 43 | -17.1 | -10.6 | 17.1 | 10.7 | 0.12 | 0.35 |
| 44 | 3 | -21.0 | -13.7 | 21.4 | 14.1 | 0.42 | 1.36 |
| 3 | 21 | 3.86 | 2.93 | -3.85 | -2.9 | 0.06 | 1.93 |
| 45 | 41 | 3.46 | 4.01 | -3.46 | -4.07 | 0.09 | 1.79 |
| 51 | 25 | -10.7 | -3.51 | 10.7 | 3.54 | 0.02 | 0.10 |
| 51 | 47 | 9.19 | 3.53 | -9.19 | -2.83 | 0 | 0.06 |
| 51 | 24 | 8.88 | 3.27 | -8.69 | -2.95 | 0.18 | 0.13 |
| 51 | 1 | -11.5 | -2.95 | 11.5 | 3.55 | 0 | 0.35 |
| 40 | 46 | -24.4 | 5.23 | 24.5 | -5.08 | 0.17 | 1.36 |
| 40 | 22 | 37.33 | -0.73 | -37.3 | 2.09 | 0 | 1.93 |
| 46 | 1 | 47.89 | 27.4 | -47.8 | -25.4 | 0 | 1.79 |
| 46 | 48 | 47.89 | 25.4 | -47.2 | -24.0 | 0.60 | 0.10 |
| 20 | 26 | 17.59 | 12.4 | -17.5 | -12.3 | 0.79 | 0.06 |
| 20 | 21 | 0.08 | -7.38 | -0.04 | 6.93 | 0.40 | 0.13 |
| 50 | 26 | 9.96 | 4.43 | -9.58 | -4.30 | 0.84 | 0.35 |
| 26 | 37 | -11.4 | -6.20 | 11.6 | 6.56 | 0.22 | 0.66 |
| 49 | 1 | 29.6 | 12.5 | -29.6 | -11.8 | 0 | 3.50 |
| 14 | 6 | 32.4 | 33.8 | -32.4 | -30.3 | 0 | 0.60 |
| 2 | 18 | 17.9 | 2.55 | -17.4 | -1.95 | 0.46 | 0.16 |
| 2 | 3 | 12.55 | -0.25 | -12.1 | 0.41 | 0.12 | 0.16 |
| 2 | 4 | 13.59 | 4.85 | -13.5 | -4.55 | 0 | 0.31 |
| 16 | 15 | -36.5 | 3.28 | 37.3 | -2.09 | 0.81 | 1.62 |
| 5 | 25 | 3.46 | 4.07 | -3.46 | -3.74 | 0 | 0.33 |
| 5 | 6 | 3.85 | 2.92 | -3.85 | -2.61 | 0 | 0.31 |
| 5 | 7 | -2.85 | 0.61 | 2.86 | -0.58 | 0.02 | 0.02 |
| 8 | 9 | -4.66 | -10.5 | 4.80 | 10.4 | 0.14 | 0.22 |
| 8 | 31 | -17.2 | -19.3 | 17.4 | 19.7 | 0.20 | 0.32 |
| 10 | 11 | 18.93 | 10.3 | -18.9 | -9.86 | 0 | 0.52 |
| Total | | | | | | 30.75 | 125.7 |

Appendix 3

Table 3. The line flow and losses of 52 bus system using SCS

| From bus | To Bus | From Bus P | Injection Q | To Bus P | Injection Q | Loss P (MW) | Loss Q (MW) |
|----------|--------|------------|-------------|----------|-------------|-------------|-------------|
| 1 | 2 | 102.0 | 75 | -100 | -84.1 | 1.11 | 2.42 |
| 2 | 3 | 97.77 | -4.64 | -94.9 | 4.46 | 1.66 | 3.77 |
| 3 | 4 | 60.21 | -8.18 | -59.7 | 5.89 | 0.42 | 0.38 |
| 4 | 5 | 13.80 | -4.43 | -13.6 | 2.24 | 0.13 | 0.24 |
| 4 | 6 | 14.16 | -5.09 | -14.0 | 2.08 | 0.09 | 0.33 |
| 6 | 7 | -17.8 | -1.71 | 17.8 | -0.62 | 0.06 | 0.34 |
| 6 | 8 | -42.5 | -6.56 | 43.1 | 5.22 | 0.64 | 3.29 |
| 8 | 9 | 178 | 19.8 | -174 | -9.12 | 2.18 | 12.1 |
| 9 | 10 | 17.17 | -9.23 | -17.0 | 5.58 | 0.13 | 0.60 |
| 9 | 11 | 12.90 | 2.07 | -12.8 | -3.99 | 0.04 | 0.16 |
| 9 | 12 | 2.55 | -15.8 | -2.45 | 8.64 | 0.10 | 0.47 |
| 9 | 13 | 2.32 | -1.9 | -2.31 | -1.93 | 0.03 | 0.01 |
| 13 | 14 | -10.3 | 22.3 | 10.4 | -23.1 | 0.87 | 0.29 |

| From bus | To Bus | From Bus P | Injection Q | To Bus P | Injection Q | Loss P (MW) | Loss Q (MW) |
|----------|--------|------------|-------------|----------|-------------|-------------|-------------|
| 13 | 15 | -48.8 | 4.89 | 49.5 | -4.91 | 0.68 | 2.20 |
| 1 | 15 | 148.9 | 33.7 | -145 | -23.9 | 3.20 | 15.9 |
| 1 | 16 | 79.25 | -0.87 | -76.6 | 7.08 | 2.63 | 11.9 |
| 1 | 17 | 93.34 | 3.94 | -91.4 | 1.77 | 1.92 | 8.73 |
| 3 | 15 | 33.77 | -18.1 | -33.5 | 13.6 | 0.23 | 0.75 |
| 4 | 18 | 13.96 | 2.44 | -13.9 | -1.35 | 0 | 1.09 |
| 4 | 18 | 17.87 | 1.19 | -17.8 | 0.18 | 0 | 1.37 |
| 5 | 6 | 0.67 | -6.24 | -0.66 | 5.07 | 0.01 | 0.02 |
| 7 | 8 | -77.9 | -12.1 | 78.8 | 15.0 | 0.89 | 4.56 |
| 10 | 12 | -17.6 | -20.0 | 17.7 | 17.6 | 0.18 | 0.85 |
| 11 | 13 | -9.93 | -4.39 | 9.95 | 2.68 | 0.02 | 0.09 |
| 12 | 13 | -0.49 | 60.3 | 1.18 | -64.0 | 0.69 | 2.27 |
| 12 | 16 | -33.4 | 8.82 | 33.6 | -10.0 | 0.21 | 0.96 |
| 12 | 17 | -48.4 | 9.17 | 49.4 | -9.77 | 0.95 | 1.32 |
| 14 | 15 | -68.8 | -9.60 | 69.7 | 10.9 | 0.87 | 2.80 |
| 18 | 19 | 4.63 | 1.39 | -4.53 | -1.23 | 0.10 | 0.16 |
| 19 | 20 | 1.23 | 0.63 | -1.22 | -0.62 | 0.06 | 0.01 |
| 21 | 20 | 1.08 | 0.39 | -1.08 | -0.38 | 0 | 0.01 |
| 21 | 22 | -1.08 | -0.39 | 1.08 | 0.40 | 0.01 | 0 |
| 22 | 23 | 9.65 | 3.11 | -9.64 | -3.10 | 0.01 | 0.02 |
| 23 | 24 | 3.34 | 1.00 | -3.32 | -1.81 | 0.02 | 0.03 |
| 24 | 25 | 7.07 | 1.71 | -7.07 | -1.09 | 0 | 0.63 |
| 24 | 25 | 6.79 | 1.65 | -6.79 | -1.05 | 0 | 0.60 |
| 24 | 26 | -10.5 | -1.55 | 10.5 | 1.61 | -0 | 0.06 |
| 26 | 27 | -10.5 | -1.61 | 10.7 | 1.93 | 0.20 | 0.31 |
| 27 | 28 | -20.0 | -2.43 | 20.3 | 2.83 | 0.26 | 0.40 |
| 28 | 29 | -24.9 | -5.13 | 25.1 | 5.51 | 0.27 | 0.38 |
| 7 | 29 | 60.09 | 13.3 | -60.0 | -10.6 | 0.00 | 2.36 |
| 25 | 30 | 7.56 | 4.63 | -7.45 | -4.46 | 0.11 | 0.16 |
| 30 | 31 | 3.85 | 2.66 | -3.77 | -2.55 | 0.07 | 0.12 |
| 31 | 32 | -2.03 | -0.35 | 2.05 | 0.39 | 0.02 | 0.04 |
| 32 | 33 | 3.81 | 1.91 | -3.80 | -1.90 | 0.08 | 0.01 |
| 34 | 32 | 7.46 | 3.79 | -7.46 | -3.10 | 0 | 0.70 |
| 34 | 35 | -7.46 | -3.79 | 7.50 | 3.55 | 0.03 | 0.32 |
| 35 | 36 | -13.5 | -6.55 | 13.6 | 6.53 | 0.10 | 0.59 |
| 36 | 37 | -17.1 | -10.6 | 17.1 | 10.7 | 0.12 | 0.35 |
| 37 | 38 | -21.0 | -13.7 | 21.4 | 14.1 | 0.42 | 1.16 |
| 37 | 39 | 3.86 | 2.93 | -3.85 | -2.9 | 0.06 | 1.63 |
| 36 | 40 | 3.46 | 4.01 | -3.46 | -4.07 | 0.09 | 1.79 |
| 22 | 38 | -10.7 | -3.51 | 10.7 | 3.54 | 0.02 | 0.10 |
| 11 | 41 | 9.19 | 3.53 | -9.19 | -2.83 | 0 | 0.06 |
| 41 | 42 | 8.88 | 3.27 | -8.69 | -2.95 | 0.18 | 0.13 |
| 41 | 43 | -11.5 | -2.95 | 11.5 | 3.55 | 0 | 0.35 |
| 38 | 44 | -24.4 | 5.23 | 24.5 | -5.08 | 0.17 | 1.36 |
| 15 | 45 | 37.33 | -0.73 | -37.3 | 2.09 | 0 | 1.93 |
| 14 | 46 | 47.89 | 27.4 | -47.8 | -25.4 | 0 | 1.79 |
| 46 | 47 | 47.89 | 25.4 | -47.2 | -24.0 | 0.40 | 0.10 |
| 47 | 48 | 17.59 | 12.4 | -17.5 | -12.3 | 0.79 | 0.06 |
| 48 | 49 | 0.08 | -7.38 | -0.04 | 6.93 | 0.40 | 0.13 |
| 49 | 50 | 9.96 | 4.43 | -9.58 | -4.30 | 0.84 | 0.35 |
| 50 | 51 | -11.4 | -6.20 | 11.6 | 6.56 | 0.22 | 0.66 |
| 10 | 51 | 29.6 | 12.5 | -29.6 | -11.8 | 0 | 2.10 |
| 13 | 42 | 32.4 | 33.8 | -32.4 | -30.3 | 0 | 0.60 |
| 29 | 52 | 17.9 | 2.55 | -17.4 | -1.95 | 0.46 | 0.16 |

| From bus | To Bus | From Bus P | Injection Q | To Bus P | Injection Q | Loss P (MW) | Loss Q (MW) |
|--------------|--------|------------|-------------|----------|-------------|--------------|---------------|
| 52 | 52 | 12.55 | -0.25 | -12.1 | 0.41 | 0.12 | 0.16 |
| 51 | 51 | -7.57 | -4.47 | 7.72 | 4.66 | 0.15 | 0.19 |
| 51 | 50 | -11.8 | -6.06 | 12.1 | 6.46 | 0.30 | 0.40 |
| 11 | 43 | 13.59 | 4.85 | -13.5 | -4.55 | 0 | 0.31 |
| 44 | 45 | -36.5 | 3.28 | 37.3 | -2.09 | 0.31 | 0.62 |
| 40 | 50 | 3.46 | 4.07 | -3.46 | -3.74 | 0 | 0.33 |
| 39 | 43 | 3.85 | 2.92 | -3.85 | -2.61 | 0 | 0.31 |
| 38 | 49 | -4.66 | -10.5 | 4.80 | 10.4 | 0.14 | 0.22 |
| 38 | 48 | -17.2 | -19.3 | 17.4 | 19.7 | 0.20 | 0.32 |
| 9 | 50 | 18.93 | 10.3 | -18.9 | -9.86 | 0 | 0.52 |
| Total | | | | | | 26.87 | 104.53 |

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Peer-review history:
 The peer review history for this paper can be accessed here:
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