International Journal of Research Publication and Reviews, Vol 6, Issue 4, pp 15557-15570 April 2025

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Improvement of the Avaliable Capability in the North Western 330kv Transmission Network Using Statcom

Uchegbu Chinenye Eberechi[1], Fagbohunmi Griffin Siji[2]

[1]**Electrical and Electronic Engineering Department, Abia State University Uturu, Nigeria**
[2]**Computer Engineering Department, Abia State University Uturu, Nigeria**
Email: ceuche@gmail.com, ce.uchegbu@abiastateuniversity.edu.ng

ABSTRACT

The study focuses on the enhancing of available transmission capacity (ATC) in the North Western 330kV transmission network using STATCOM FACTS which is being modeled and installed and implemented in the power system toolbox (PSAT) The objective is to assess and optimize transfer capability in the power system between different areas within the network. Through the utilization of PSAT, various scenarios and simulations were conducted to analyze the network's performance under different operating conditions. The study assessed the impact of load, stability of the voltage, and the system control reactive power on the ATC. Based on the results obtained from the simulations, several measures were proposed and analyzed to improve the ATC in the North Western 330kV transmission network. These included Comparative Analysis of entire network of the Power system with STATCOM FACTS and with no STATCOM optimal power flow voltage analysis, of the system power profile also the active and reactive power loss with STATCOM FACTS. Overall, this research contributes to the ongoing effort in improving the performance of power transmission networks, ultimately ensuring a more reliable and secures supply of electricity to consumers. However, using STATCOM has proven FACTS that the device is capable of improving voltage stability and transfer capability, especially in weak grids like Nigeria's. However, the application of PSAT toolbox for dynamic analysis, particularly in the North-Western 330kV network, remains limited. This study address this by simulating STATCOM in PSAT, evaluating its impact on bus voltage profiles and transfer capability under both steady-state and faulted conditions and an improvement of 5% was achieved.

Keywords: Transmission Network, STATCOM Facts, Power System Analysis and tools (PSAT) Available Transmission Capacity(ATC), Power system library, MATLAB.

1 Introduction

The Nigerian electricity system has been plagued by persistent issues for many years, such as significant power losses and a very limited capacity of electricity to transport energy from generating stations to distribution level. Restructuring is now taking place in the Nigerian power sector, particularly in the generation and distribution systems. In 2023, Hassan N. et al., The transmission network's stability margin has decreased as a result of the deregulation of electricity distribution and marketing, raising the possibility of cascading outages and blackouts (voltage collapse). Voltage collapse happens when power systems are overloaded, malfunctioning, or experiencing a lack of reactive power. Voltage collapse is a type of system instability that can be brought on by numerous parts of the power system. In essence, For the purpose of power marketing, transfer capability (ATC) is a measurement of the additional transmission capacity above the base case power transfer. High power electronic controls that may inject or absorb reactive power in accordance with system requirements are one way to address the issue. One of the most significant sources of reactive power is the FACTS (Flexible AC transmission system) device. These tools enable flexible AC transmission system operation without putting the system under stress.The improvement of the transfer capabilities using STATCOM is the main focus of this study. The Nigerian 330kV transmission network's north western region served as the model for the power system network. The Power System Analytical Toolbox in SIMULINK was used to create the model. Modeling the ATC of the power system network with and without FACTS and comparing the results allowed researchers to gauge how much the STATCOM would improve things. The charts and plots produced for this study were created using the Mat Lab application interface.

2 A Review

In the 1970s, Nigeria experienced an oil boom, which led to increased government revenue. However, despite this economic growth, the power sector still faced challenges. The existing power infrastructure was outdated, and there was a lack of investment in new power plants and transmission lines.

To address these issues, the Nigerian government embarked on a series of power sector reforms in the 1990s. The reforms aimed to attract private investments, improve efficiency, and increase access to electricity. However, despite these efforts, the power sector continued to face challenges such as inadequate funding, poor maintenance of infrastructure, and a high level of technical and commercial losses. These issues resulted in frequent power outages and limited access to electricity for many Nigerians. Recognizing the need for further reforms, the Nigerian government initiated the Power Sector Reform Act in 2005. The generation and distribution sectors were also privatized, allowing for private investments and competition.

Despite these reforms, Nigeria's power sector still faces challenges such as inadequate generation capacity, insufficient gas supply, and inadequate transmission and distribution infrastructure. Efforts are ongoing to address these issues and improve the power system network in the country.

Voltage stability and available power transfer capability are critical issues in high-voltage transmission systems, especially in developing countries like Nigeria. The increasing demand for electricity, without a commensurate expansion of transmission infrastructure, has led to voltage instability and underutilization of available transmission corridors. In this context, Flexible AC Transmission Systems (FACTS), such as the Static Synchronous Compensator (STATCOM), offer promising solutions. This review focuses on the evolution, control strategies, and simulation of STATCOM using the **Power System Analysis Toolbox (PSAT)** to enhance system performance.

2.2 Evolution of Reactive Power Compensation

Reactive power compensation techniques have evolved significantly, from passive devices like capacitors and reactors to dynamic compensators like SVC (Static VAR Compensator) and STATCOM. While SVCs use thyristor-switched components, STATCOM utilizes voltage source converters (VSCs), offering faster response and more accurate voltage regulation.

Key Milestones:

- 1960s–1980s: Use of mechanically switched capacitors and reactors.
- 1990s: Emergence of thyristor-controlled FACTS devices like SVCs.
- 2000s onwards: Adoption of VSC-based FACTS like STATCOM for dynamic support.

2.3 STATCOM Technology:

STATCOM operates as a shunt-connected VSC that injects or absorbs reactive power to regulate bus voltage. Unlike SVC, STATCOM performance is less sensitive to system voltage, allowing full reactive power support even during voltage sags. Its advantages are Faster dynamic response, Compact size, Superior low-voltage performance. Researchers such as Hingorani et.al 2000 have extensively demonstrated that STATCOM can outperform traditional shunt compensators, especially during fault or transient conditions.

2.3.1 Voltage Stability in the Nigerian 330kV Network: The Nigerian power grid, particularly in the North-Western region, suffers from long transmission lines, weak voltage profiles, and poor load ability due to a lack of dynamic VAR support. Studies by Momoh et al. (2013) and Okoro et al. (2017) identified that voltage dips, especially during peak demand, are common at substations such as Kaduna, Kano, and Sokoto.

2.4 Research Gaps

Despite numerous studies, the gap remains that Very few studies have focused on the North-Western 330kV network using localized load and line data and there are Limited use of PSAT’s CPF to quantify available transfer capability (ATC) improvement using STATCOM

3. MATERIALS AND METHOD

3.1 MATERIAL

a.MATLAB/Simulink: Ideal for detailed time-domain simulations.

b.DIgSILENT PowerFactory: Used for commercial-level planning.

c.PSAT Toolbox (Power System Analysis Toolbox): Suitable for MATLAB-based power flow, continuation power flow (CPF), and small-signal stability studies.

d.Spreadsheet of the Nigerian 330kV buses with the source and transmitted active and reactive power, the voltage values and the transmission line performance.

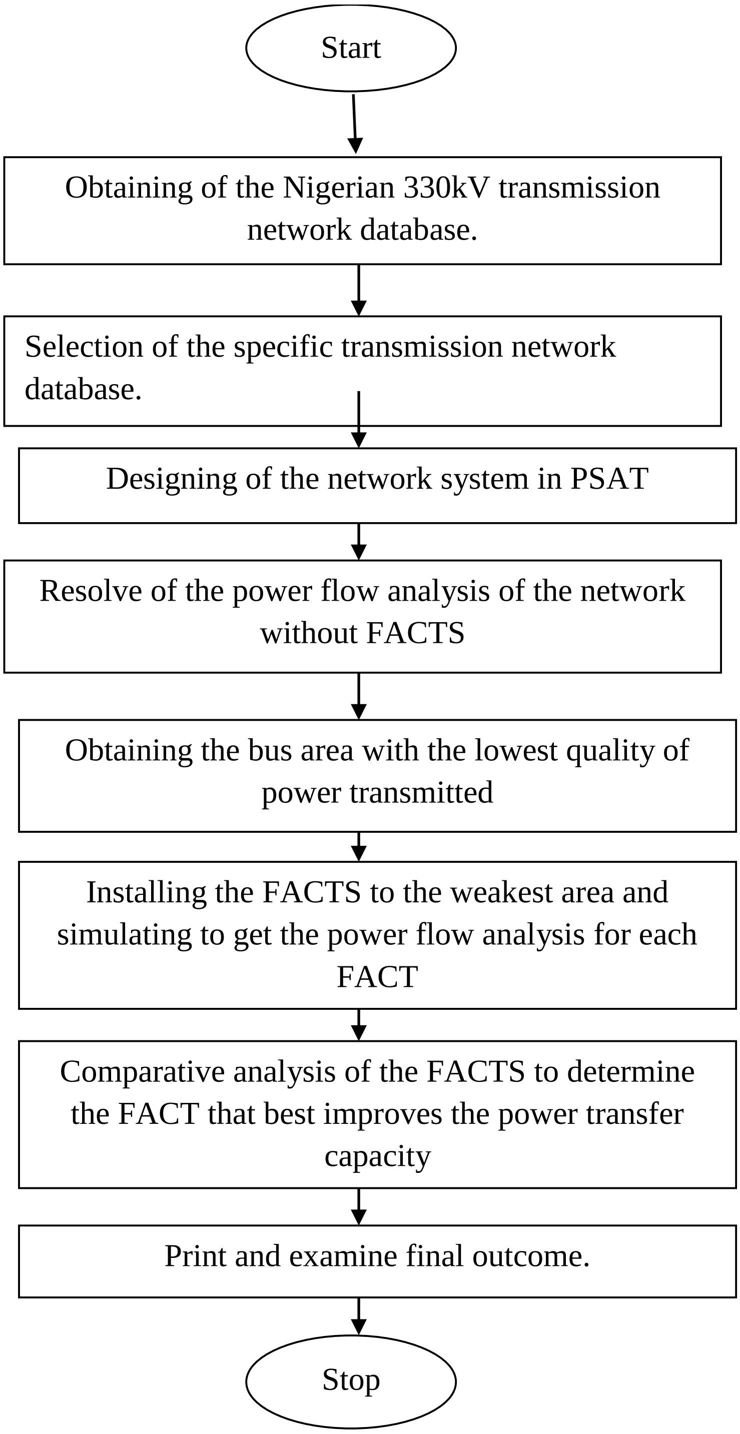
e. A laptop with Mat Lab software application of which power system analytical tool was installed and Microsoft office component installed.

3.2 METHODS

3.2.1 Research Procedure

The main focus of this study is to regulate the ATC on the power system. The facts and statistics employed that is from the Nigerian 330kV transmission line network was gotten from the NCC organization in Oshogbo, Osun state, Nigeria. An aggregate of 6 buses were laid out in the bounds of the northwestern part of Nigeria. The network system was designed in PSAT in Mat Lab environment and the flow analysis was gathered after simulating without FACTS. STATCOMs was installed in the precise area with the lowest transmitted power for electricity transfer advancement.

Comparative analysis on total transfer capacity of the FACTS was computed with the device selected. The flow chart of the research procedure is shown in figure 3.1.



Data 3.1 : Flow diagram of Research Procedure

3.2.2 Database Collection

The data acquired for this research was a Nigerian 330kV North Western transmission power network gotten from NCC organization in Oshogbo,osun state. This data was procured in excel format as shown in figure 3.2.

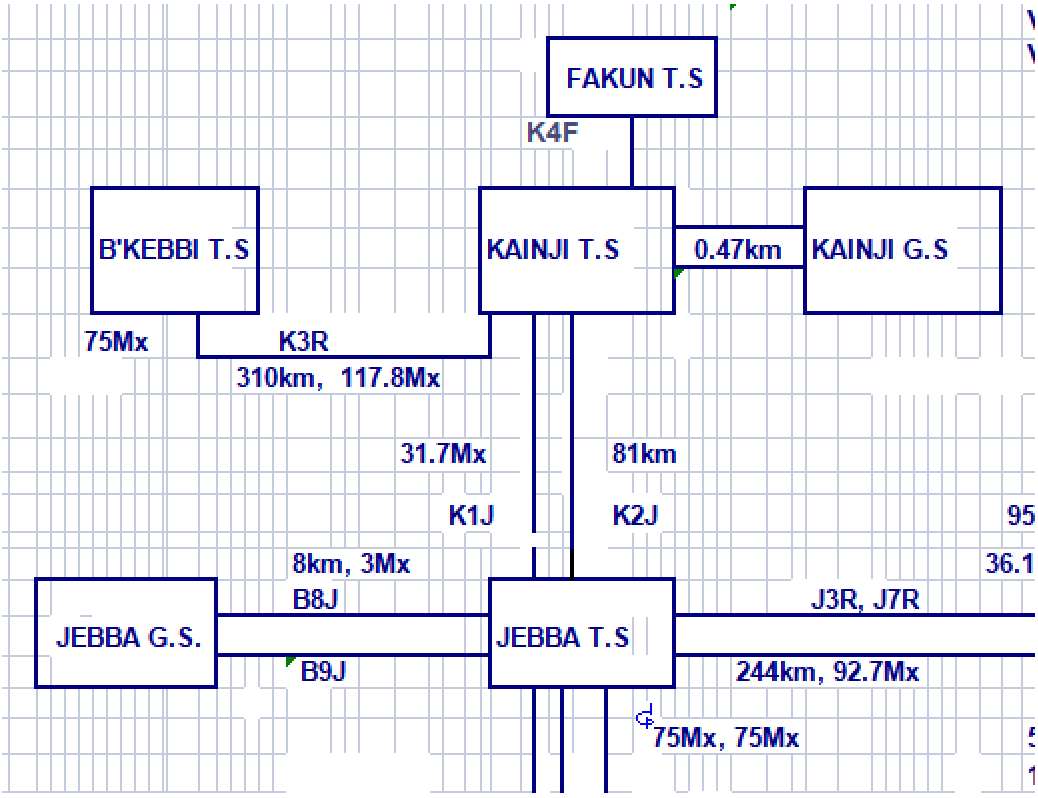


Figure 3.2: Nigerian 330kV North western power system network .

The buses selected as shown in figure 3.3 were Jebba GS, Jebba TS, Kainji TS, Kainji GS, Benin Kebbi TS and Fakun TS.The buses selected buses formed the power system network that was modeled in power system toolbox.

3.2.3 Modeling of the Transmission system network with PSAT

The modeling of the transmission system network was outlined in the steps below.

Step 1: Call up the Mat Lab environment once Mat Lab is installed, the icon is saved on the desktop. Click on the icon for the Mat Lab application to load in the system's desktop.

Step 2: Install PSAT tool and execute

The PSAT was downloaded from "Federico Milano's'' website and installed as a Mat Lab tool and then called up by entering the command ''PSAT'' in the Mat Lab's command window. The PSAT environment is displayed in data 3.4.

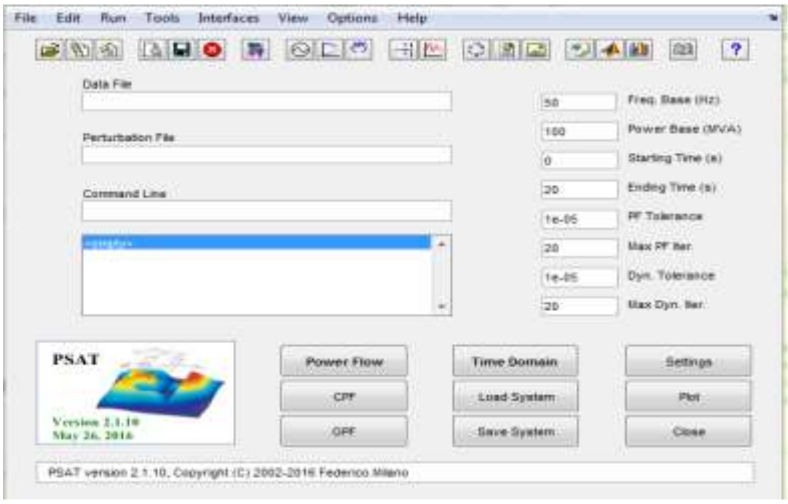


Figure 3.4: PSAT Environment

Power system tool library where all the transmission network components were selected is displayed in data 3.5.

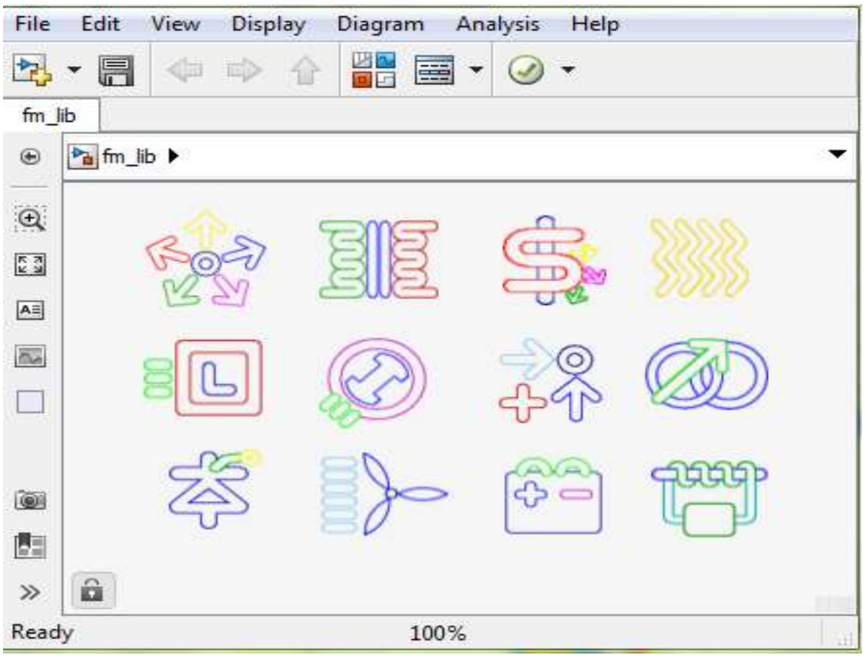


Figure 3.5 : Power system library

The power library displayed in figure 3.5 has the transmission lines, buses, loads, generators and FACTS. Only the scope block was obtained from the Simulink library.

The PSAT modeling environment is displayed in data 3.6.

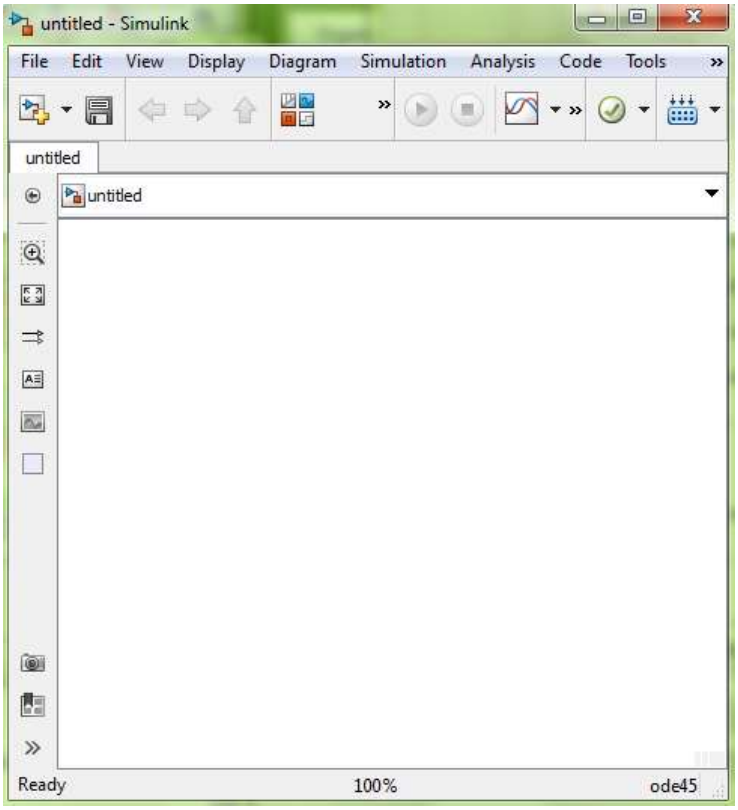


Figure 3.6: PSAT model library

The power system component needed for this study was assembled at the model environment shown in figure 3.6. The model environment with the power system network of the selected region is displayed in data 3.7.

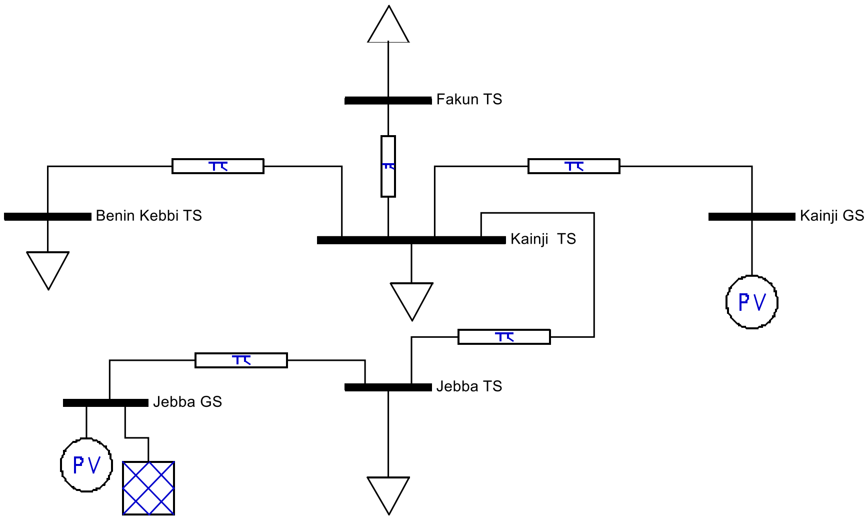


Figure 3.7: PSAT representation of the power system network.

From figure 3.7, the slack parameter was assigned to Jebba GS. The generation station in this model includes Jebba GS and Kainji GS. While the transmission stations are Jebba TS, Kainji GS, Fakuni(T.S), Benin Kebbi TS, and Fakun TS. The model in figure 3.7 was saved.

Step 3: Perform the total power transfer capability analysis To achieve this, the saved model was uploaded to the PSAT environment shown in figure 3.7, the 'power flow' model tab was clicked in order to enable the system perform Newton-Raphson power flow analysis on the power system model. The PSAT environment indicating optimal power transfer capacity simulation completion with the conditions needed to achieve the outcome is revealed in figure 3.8.

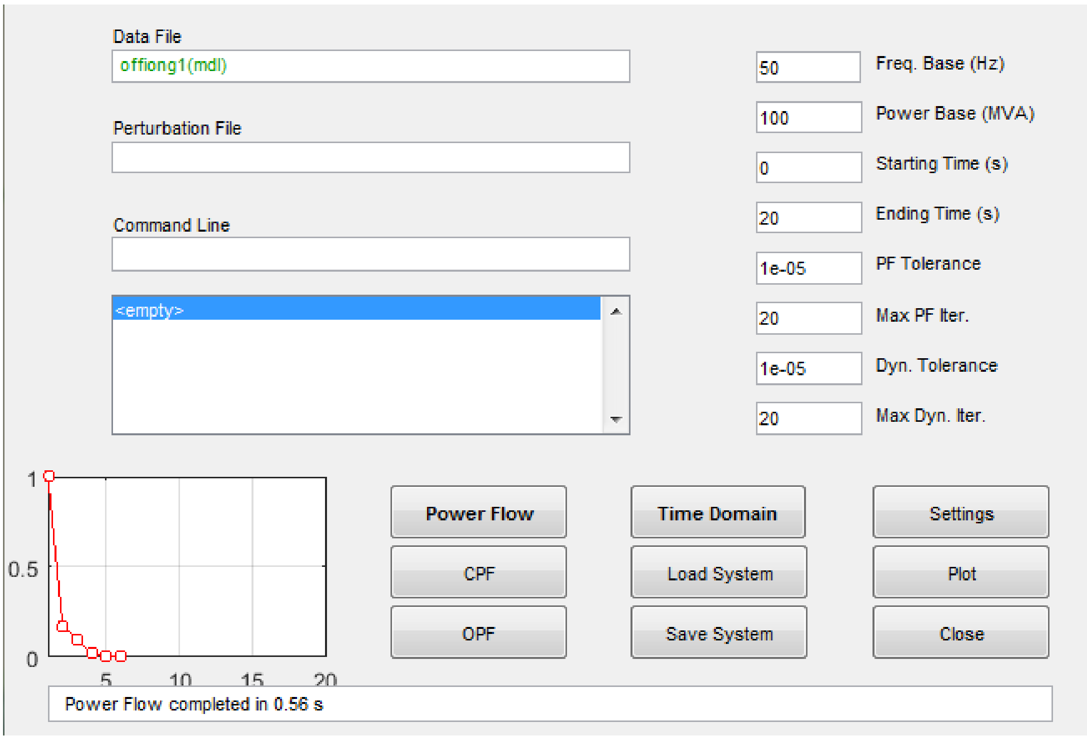


Figure 3.8: Completed total power transfer capacity simulation

From figure 3.8, it can be seen that the power flow was completed in 0.56 seconds at base frequency of 50Hz and base power of 100MVA.

Step 4: Obtain the area with the lowest active and reactive energy transfer. The buses with the least power transfer was obtained from the load flow analysis outcome shown in chapter four.

Step 5: Insert the FACTS to the weak bus: STATCOM FACTS was inserted in the location with the least load transfer. However, the network system with STATCOM was revealed in figure 3.9.

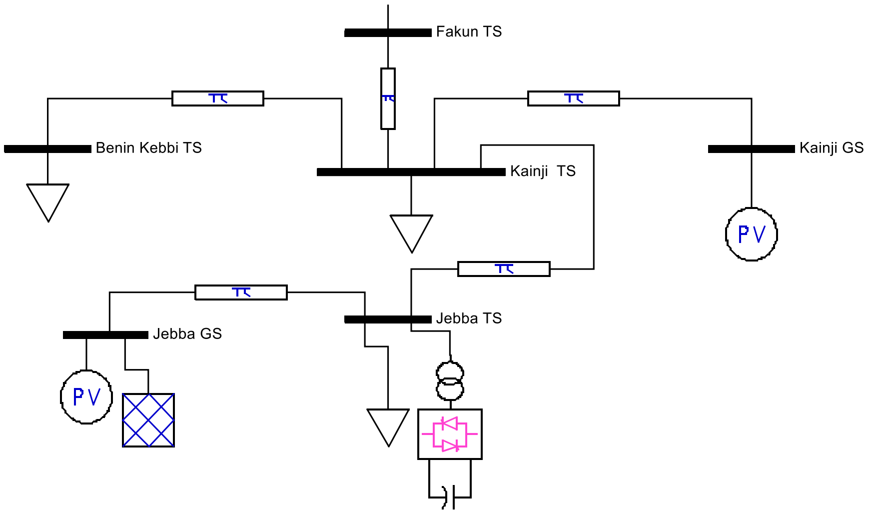


Figure 3.8: Power system network with STATCOM

The STATCOM installed and implemented in the system network as shown in figure 3.9. the essence was for the FACTS to improve the existing total transfer capability.

It can be seen that all the FACTS were inserted at Jebba transmission station because it has the lowest amount of power transferred.

Step 6: Determine the total transfer capacity of the FACTS device utilized.

This was done by observing and determining the percentage improvement achieved on the location(s) with the least amount of power transferred in accordance with the FACTS device installed. The outcome was presented in chapter four which was the result section of the study.

4 RESULTS AND ANALYSIS

4.1.1 Power transfer capacity of the system without FACTS

The current profile of the network system without FACTS is displayed in table 4.1.

Table 4.1: current profile of the system without FACTS

Bus number	Bus Location	Voltage profile (pu)
1	Jebba GS	1.0000
2	Jebba TS	0.9640
3	Kaiji GS	0.9899
4	Kainji TS	0.7773
5	Benin Kebbi TS	0.6884
6	Fakun	0.7998

From table 4.1, the location with least voltage value was Benin Kebbi. The bar chart of the voltage profile is displayed in data 4.1.

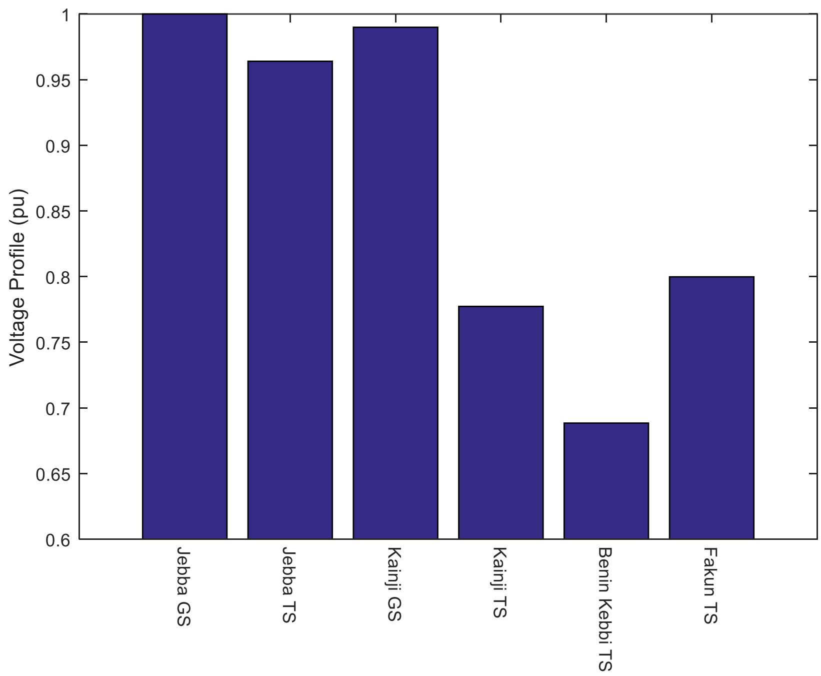


Figure 4.1: Voltage profile of the buses

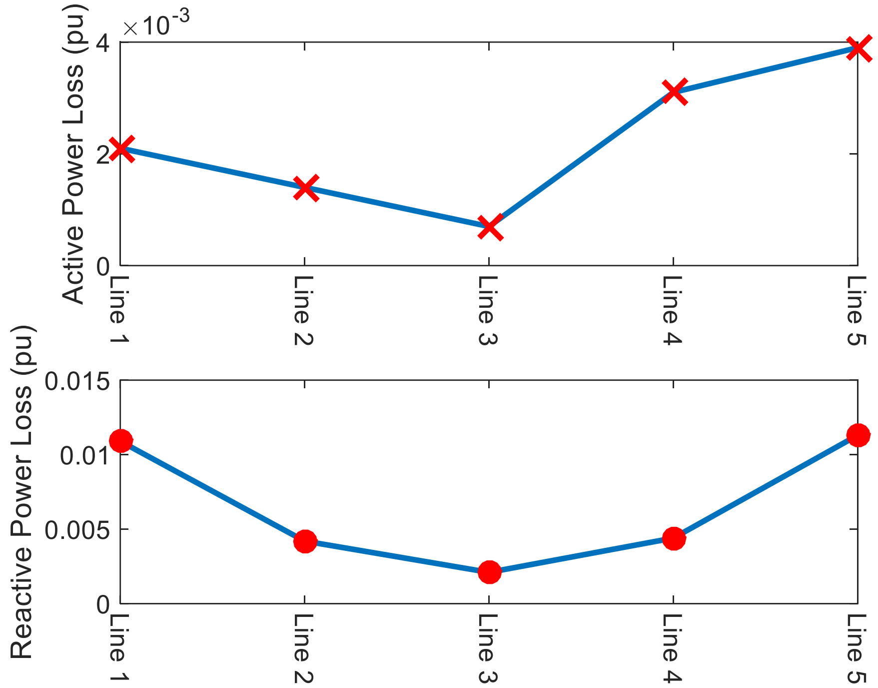
From figure 4.1, it can be seen that the least bus voltage was in Benin Kebbi and this affirms with the values in table 4.1. The active and reactive power losses obtained for the transmission lines were given in table 4.2

Table 4.2: The active and re-active power losses

Line	From Bus	To Bus	Active Power (pu)	Reactive Power (pu)
1	'Jebba GS	'Jebba TS	0.0021	0.0109
2	Jebba TS	Kainji TS	0.0014	0.0042
3	Kainji TS	Kainji Fakun TS	0.0007	0.0021
4	Kainji TS	Benin Kebbi TS	0.0031	0.0044
5	Kainji TS		0.0039	0.0113

The bar chart of the current profile.

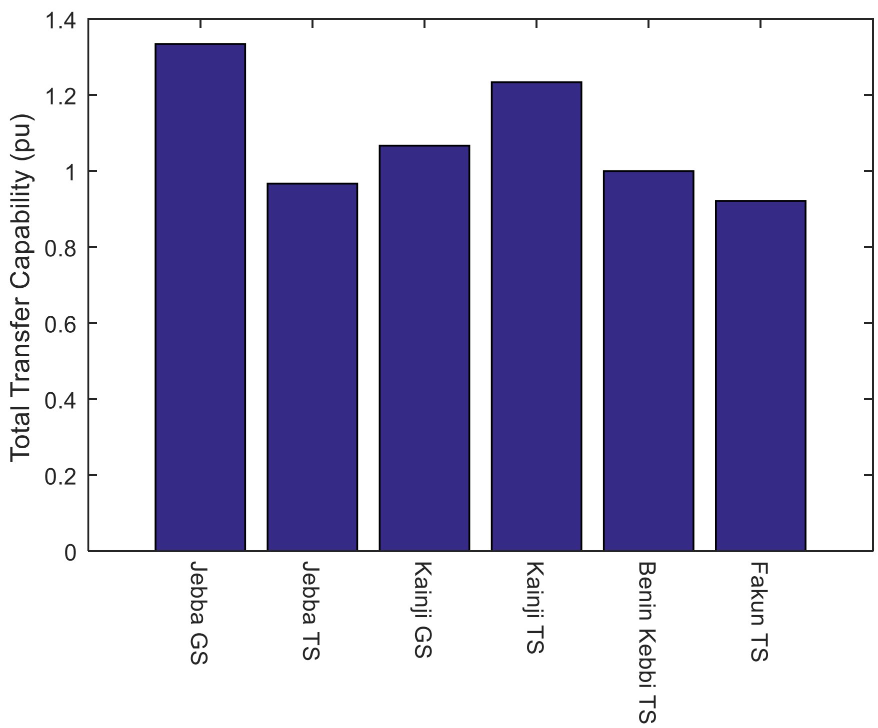
The amount of active power loss and re-active power loss for each location on completing the power flow simulation is displayed in figure 4.2.



Data 4.2: active and re-active power loss without FACTS

From figure 4.2, the transmission line with highest amount of losses was line 5 which was the line connecting Kainji TS and Benin Kebbi TS.

The total power transfered was shown in figure 4.3.



Data 4.3; Total transfer capability for the system without FACTS

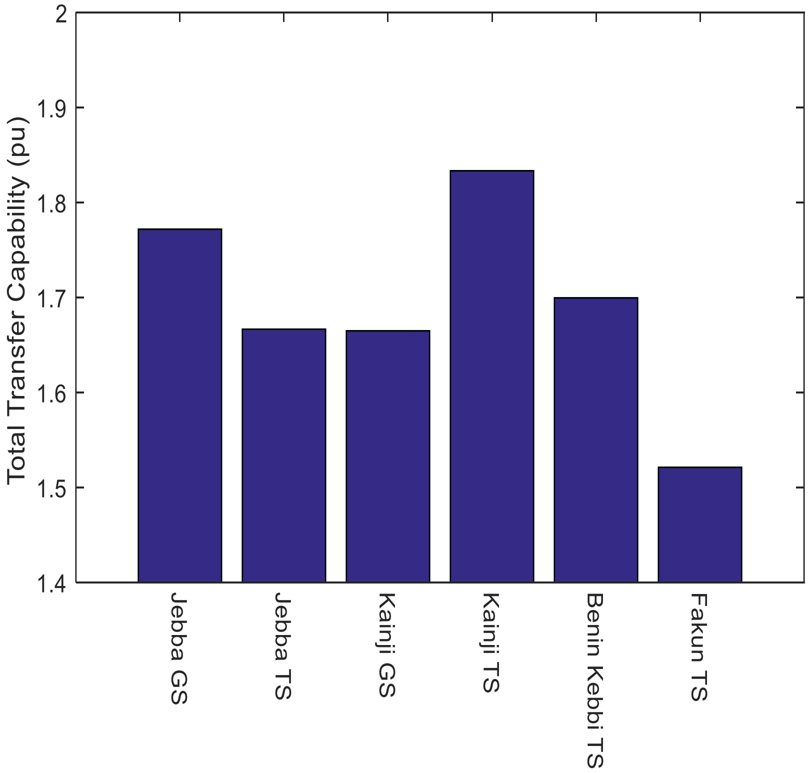
4.2 Total transfer capacity of the system with STATCOM

The voltage profile of the network system without FACTS is displayed in table 4.3.

Table 4.3: voltage profile of the network system with STATCOM.

Bus number	Bus Location	Voltage profile (pu)
1	Jebba GS	1.0000
2	Jebba TS	0.9840
3	Kaiji GS	0.9919
4	Kainji TS	0.9773
5	Benin Kebbi TS	0.9884
6	Fakun	0.9998

From table 4.3, the location with least voltage value was Benin Kebbi. The bar chart of the voltage profile is shown in data 4.4.



Data 4.4: Voltage profile of the buses with STATCOM/

From figure 4.4, it can be seen that the voltage profile has improved especially in Benin Kebbi with the installation of STATCOM FACTS and this affirms with the values in table 4.3. The active and re-active power losses obtained for the transmission lines were with STATCOM was shown in table 4.4.

Table 4.4: The active and reactive power losses with STATCOM

Line	From Bus	To Bus	Active Power (pu)	Reactive Power (pu)
1	'Jebba GS	'Jebba TS	0.0008	0.079
2	Jebba TS	Kainji TS	0.0010	0.0032
3	Kainji TS	Kainji GS	0.0003	0.0011
4	Kainji TS	Fakun TS	0.0011	0.0024
5	Kainji TS	Benin Kebbi TS	0.0017	0.0073

The bar chart of the current

The quantity of active power loss and re-active power loss for each location on completing the power flow simulation is shown in figure 4.5.

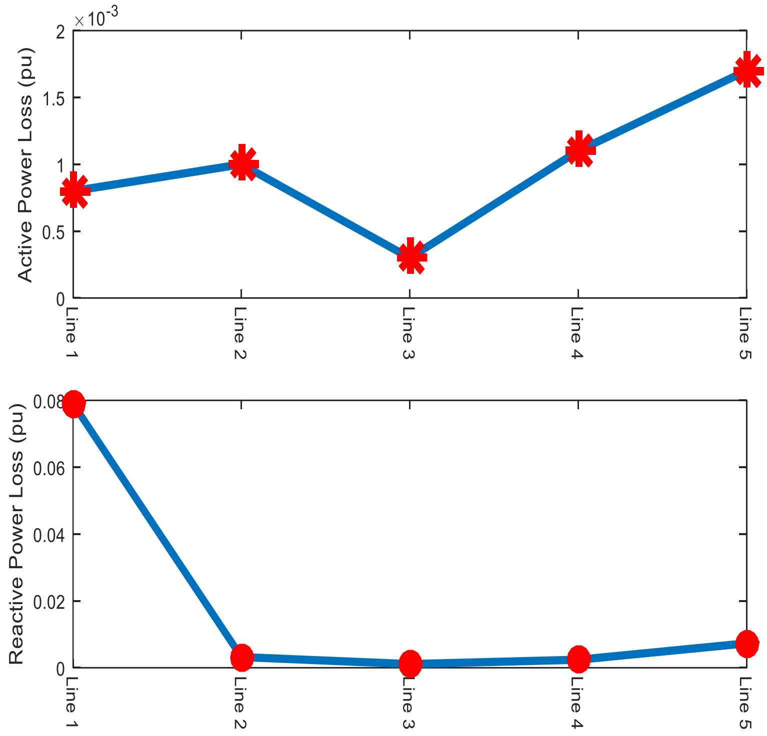
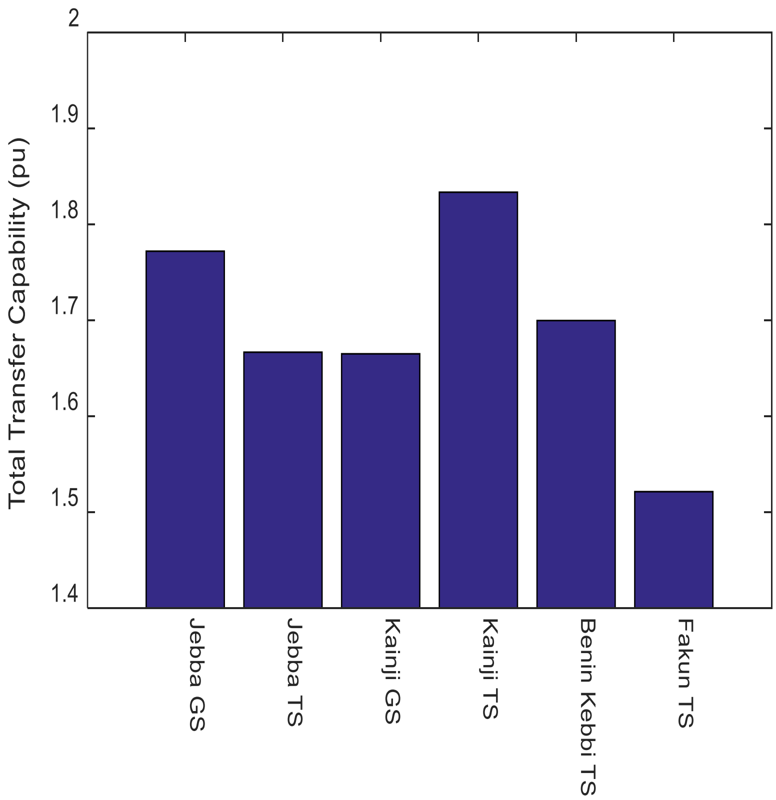


Figure 4.5: active and reactive power loss with STATCOM FACTS

From figure 4.5, the transmission line with highest amount of losses which was line 5 was normalized as shown in the figure with the introduction of STATCOM.

The total power transfered was shown in figure 4.6.

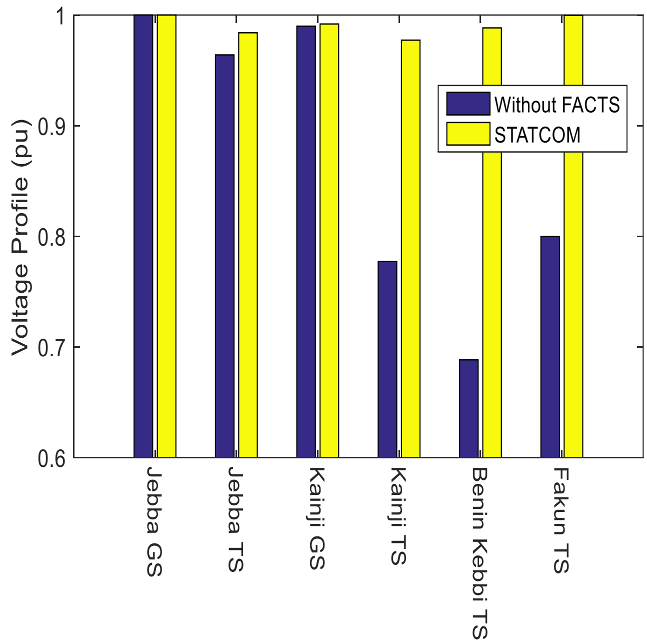


Data 4.6; Total transfer capability for the system with STATCOM FACTS

The total power transferred was improved with the introduction of STATCOM FACTS. The least total power transferred was more than 1.5pu.

4.3 Comparative Analysis

The comparative current profile of the network system with and without FACTS is displayed in figure 4.7.



Data 4.7; Current profile of the power system

Figure 4.7 showed the current profile of the network system for with and without STATCOM. It was observed that the profile was normalized with the implementation of STATCOM. The comparative plot of the power losses of the system for with and without FACTS was shown in figure 4.8.

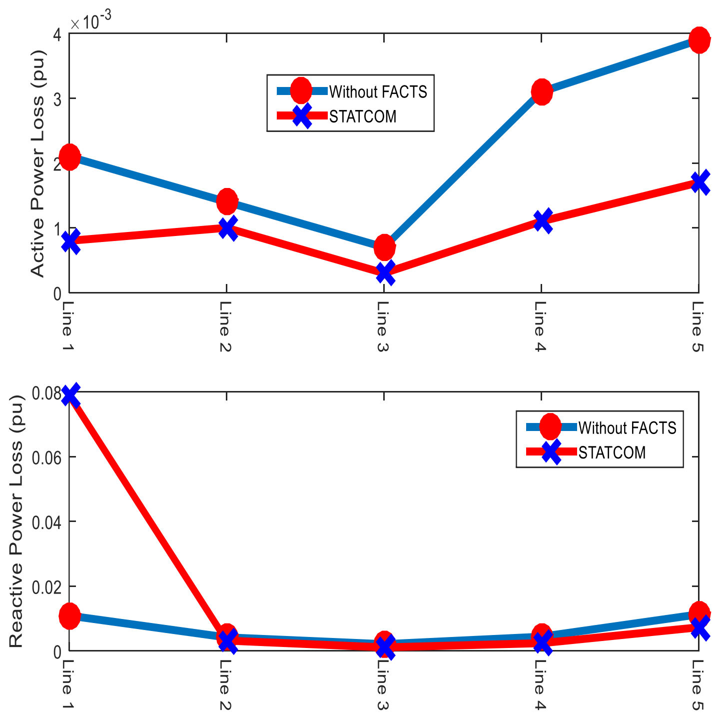


Figure 4.8; Comparative analysis of the power system network for with and without FACTS

The introduction of STATCOM to the system reduced the power losses to the minimum as shown in figure 4.4. hence, this implies that STATCOM FACTS is effective in minimizing power losses (especially active power losses). Comparative plot for the total transfer capability was shown in figure 4.9.

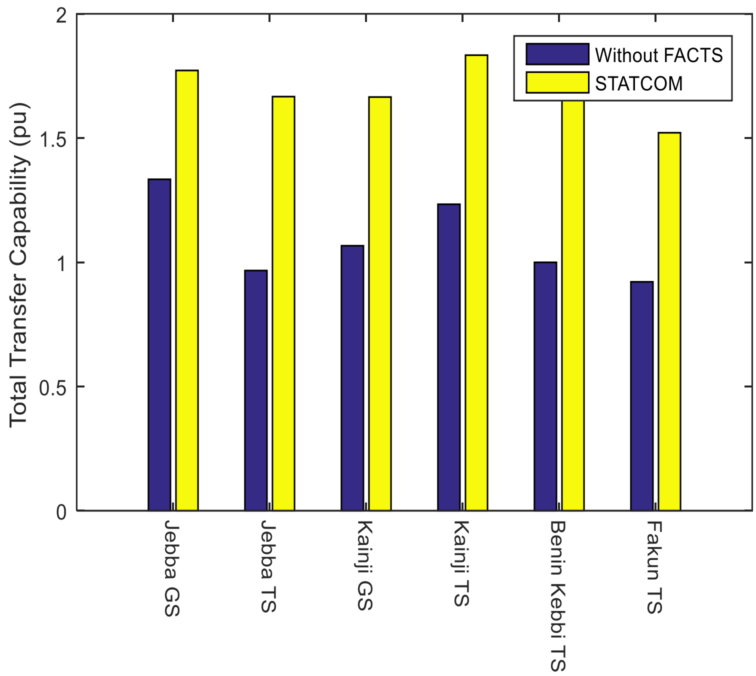


Figure 4.9; TTC with STATCOM FACTS

The TTC comparative bar chart shown in figure 4.9 showed that the implementation of STATCOM FACTS led to increase in TTC and as such STATCOM should be installed in realtime so as to increase the total power transfer.

5. Conclusion

This study has demonstrated that the application of Static Synchronous Compensator (STATCOM) technology within the North Western 330 kV transmission network can significantly improve the network's available transmission capability. By providing dynamic and fast-acting reactive power compensation, STATCOM enhances voltage stability, reduces transmission losses, and mitigates voltage fluctuations caused by load variations and contingencies. Load flow and contingency analyses clearly show that strategic placement of STATCOM units alleviates voltage violations and improves system stability margins, particularly under stressed operating conditions.

Furthermore, the simulation results affirm that STATCOM contributes to better power quality and reliability by supporting both steady-state and transient performance of the network. Its ability to provide both capacitive and inductive reactive power without the need for large switching operations makes it a superior alternative to conventional compensation methods. Overall, STATCOM deployment presents a technically viable and economically beneficial solution to address the growing demand and stability challenges facing the North Western 330 kV transmission corridor.

6. Recommendations

It is recommended that STATCOM devices be installed at critical nodes within the North Western 330 kV network—specifically at buses experiencing frequent undervoltage conditions or high reactive power demands. Load flow studies should guide site selection for maximum impact. And to fully leverage STATCOM's fast response capabilities, integration with PMU-based WAMS should be considered. This would allow for real-time monitoring and control, further enhancing voltage stability and network reliability Also Combining STATCOM with other Flexible AC Transmission Systems (FACTS) devices such as SVCs or TCSCs may offer enhanced benefits, particularly in complex or heavily loaded regions of the grid and a Utility planners and regulators should develop frameworks that support investment in advanced grid technologies like STATCOM, especially in regions where network expansion is constrained by right-of-way or environmental concerns.

References

Adeoye, A., & Folorunso, K. O. (2020). Voltage stability improvement using STATCOM: A PSAT-based analysis. *Nigerian Journal of Technology*, 39(2), 112–119.

Adetokun, B. B., Muriithi, C. M., & Ojo, J. O. (2020). Voltage stability assessment and enhancement of power grid with increasing wind energy penetration. International Journal of Electrical Power & Energy Systems, 120, 105988.

Adewuyi, O. B., Shigenobu, R., Senjyu, T., Lotfy, M. E., & Howlader, A. M. (2019). Multiobjective mix generation planning considering utility-scale solar PV system and voltage stability: Nigerian case study. IEEE Access, 7, 12626-12640.

Ajewole, T. O., & Folly, K. A. (2021). Voltage stability analysis of the Nigerian 330-kV transmission network using static and dynamic approaches. Electric Power Systems Research, 190, 106859.

Bello, S., & Muhammad, M. A. (2022). Power transfer enhancement in the Nigerian grid using FACTS devices in PSAT. *IEEE African Journal of Computing & ICT*, 15(4), 77–83

Hassan, N., Ibrahim, U., & Ahmed, A. (2020). Performance analysis of STATCOM in improving available transfer capability of power systems. Journal of Electrical Engineering & Technology, 15(1), 133-144.

Hingorani, N. G., & Gyugyi, L. (2000). *Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems*. IEEE Press.

Momoh, A. O., Ogbuefi, J. O., & Nwosu, C. O. (2013). Voltage instability issues in the Nigerian power network. *Nigerian Journal of Engineering*, 20(1), 10–18.

Nagpal, M., Bhole, K. S., & Ranade, S. J. (2019). Application of FACTS devices for ATC enhancement in competitive electricity markets. International Journal of Emerging Electric Power Systems, 20(3), 1-15.

Okoro, C. O., & Anyanwu, G. A. (2017). Assessment of voltage profiles in the Nigerian 330 kV transmission network. *International Journal of Electrical Power & Energy Systems*, 92, 85–93. https://doi.org/10.1016/j.ijepes.2017.04.003 *(Include DOI if available)*

Oladimeji, K., Kola, A., & Adewuyi, O. (2019). Impact of STATCOM on available transfer capability enhancement in Nigerian 330kV grid system. Nigerian Journal of Technology, 38(4), 974-983.

Samuel, I. A., Katende, J., Awosope, C. O. A., & Awelewa, A. A. (2017). Prediction of voltage collapse in electrical power system networks using a new voltage stability index. International Journal of Applied Engineering Research, 12(2), 190-199.

Tumiran, T., & Jasa, L. (2021). Static synchronous compensator (STATCOM) for improving power system stability: A comprehensive review. Indonesian Journal of Electrical Engineering and Computer Science, 22(3), 1459-1470.

Uchegbu Chinenye Eberechi, Inyama Kelechi, Kalu Peace Onyekachi (2023) Effective Power Restoration in the National Grid, Using Interconnected System (Neural Network Intelligence): A Review of the Nigerian Grid System. American Journal of Electrical Power and Energy Systems 2023; 12(3): 40-50 http://www.sciencepublishinggroup.com/j/epes doi: 10.11648/j.epes.20231203.11 ISSN: 2326-912X (Print); ISSN: 2326-9200 (Online

Yunus, A. M. S., Masoum, M. A., & Abu-Siada, A. (2018). Application of STATCOM to improve the high-voltage ride through capability of wind turbine generator. IEEE Transactions on Industry Applications, 54(3), 1808-1815.