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Power Transfer Capability Enhancement of The Nigerian 330kV Transmission Network with SVC FACTS Controller

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ABSTRACT: The lack of installation of generation stations has affected the transmission system of the Nigerian power network as the load demand increases. This has led to increased power losses and power congestion on the lines which has affected the available transfer capacity (ATC) of the power system network. Due to these increasing issues, SVC FACTS controller was utilized in this paper to improve ATC. The ATC of the system without FACTS controller was obtained after modeling the system using the data obtained from NCC osogbo with NEPLAN software. The relationships between the cumulative distances and the ATC values for each line were obtained and the best polynomial order being the seventh order at R-square of 99.08% was optimized with genetic algorithm where the optimal ATC was 74.31MW at summative distance of 954.5km which was on line 8 (Benin TS to Oshogbo TS) with SVC FACTS implemented at Osogbo TS. The introduction of the compensator reduced the reactive power losses by 32%, real power losses by 36% and improved on the ATC by 18%.

KEYWORDS: FACTS, NEPLAN, power flow, power transfer capability, SVC

I. INTRODUCTION

The existing power system in Nigeria consist of generation stations, transmission stations and substations and distribution with majority of the generation plants being thermal and gas plants (Jiang, Chow, Edris, Fardanesh & Uzunovic, 2010; Das, Singh & Mishra, 2023; Awah, Okoro, Nkan & Okpo, 2022). The records from the national control center Osogbo through (PHCN, 2018) showed that some of the power generation plants are not functional either as a result of lack of maintenance or inability to implement protective measures with the occurrence of fault on the lines. This had led to reduction in the amount of power supply. Further findings made from the literature especially in (Sahraei-Ardakani & Blumsack, 2016; Sarraei-Ardakani & Hedman, 2017; Lyu, He, Tan, Lin, Luo & Yan, 2023), showed that the Nigerian transmission and distribution line currently witnesses power system congestion during transmission and distribution leading to the high rate of epileptic power supply and the inability to meet up with the ever increasing load demand in Nigeria. The major parameter utilized in testing the rate of power sent from the generation station and the amount received in the transmission stations was the available transfer capability (ATC) (Yang, Jiang, Han, Tan & Liu, 2023; Elgebaly, Taha, Azmy & El-Ghany, 2021). Some of the gas plants for power generation installed has not been able to generate electricity due to the absence of gas and at the process of meeting up the load demand (Ji, Gao, Zhou & Li, 2009; Nkan & Okpo, 2016; Oduleye, Nkan & Okpo, 2023; Okoro, Abunike, Akuru, Awah, Okpo, Nkan, Udenze, Innocent & Mbunwe, 2022), the power engineers tried to distribute power beyond the existing infrastructural capacity which has led to the collapse of some of the national grids (Jameson, Nkan & Okpo, 2024; Edifon, Nkan & Ben, 2016; Abunike, Umoh, Nkan & Okoro, 2021). To determine the ATC of the power system network, the power flow analysis especially the real power (in W) must be determined and then utilized in calculating the ATC. A low ATC implies a significant loss of power on the transmission network and affects the financial sustainability and social welfare of the affected country of state or state (Ji, Gao, Zhou & Li, 2009). The fundamental and most effective way of reducing power congestions and improving the ATC of the power system network has been the utilization of flexible AC transmission system (Takahashi, Hiraki, Iwamoto, Morita & Sakamoto, 2009; Mohan, Singh & Suresh, 2018). The use of FACTS ensures that a large amount of power generated would be transmitted and in doing so, reduces the power losses, improves the voltage profile and increases the power transfer capacity of the power transmission from the generation station to the load stations. The use of FACTS in improving the transmission of electricity from has been described to be a good alternative to installing new power plants which was known to be capital intensive (Shukl & Singh, 2023; Castilla, Velasco, Miret, Borrell & Guzman, 2022). In this paper, the power flow analysis and the ATC of the Nigerian 330kV transmission system was determined and a comparative analysis was carried out of the power system network for with and without the use of SVC FACTS. Prior to the placement of the FACTS, the power flow analysis was determined for the power system without FACTS and genetic algorithm optimization technique was deployed in determine the optimal location for installation of the SVC FACTS. The FACTS was implemented and simulated to determine the level of ATC improvement. The application utilized for the simulation of the power system network in this paper was NEPLAN and the data utilized was obtained from the national control center in Osogbo Osun state which was the central location for the control of the transmission power system network of Nigeria (PHCN, 2018).

II. REVIEW OF RELATED LITERATURE

(Wokoma, Osegi & Idachaba, 2019; Okpo & Nkan, 2016; Okpo, Nkan, Okoro & Akuru, 2021; Innocent, Nkan, Okpo & Okoro, 2021) predicted the voltage collapse point of the transmission system with quadratic line voltage stability index (q-LVSI) model and with machine learning modeling technique referred to as the AMI. These model were implemented on some of the buses of the Nigerian 330kV transmission system. To determine the performance of the model utilized, the author compared the outcome of the machining learning and q-LVSI technique to the GMDH time-series (Group Method of data Handling for time series model) which was a novel model developed by the author in the determination of the power transfer capability of the power system considered. (Airoboman, John, Araga, Abba-Aliyu & Aderibigbe, 2021; Ezeonye, Okpo, Nkan & Okoro, 2020; Innocent, Nkan, Okpo & Okoro, 2021) modeled the power system network of the Nigerian 330kV power system involving shiroro to jebba to Osogbo transmission system. The essence of the modeling and analysis was determined the stability in voltage and power with steady state and dynamic methods. The results by the author showed that the voltage was minimal at Jebba and osogbo stations for steady state outcome and the dynamic outcome showed that Osogbo and Jebba stations had the least reactive at varying fault scenarios. (Nkan, Okoro, Obi, Awah & Akuru, 2019; Nkan, Okoro, Awah & Akuru, 2019) used SVC and STATCOM separately in the transient stability improvement of the 48-bus network of the Nigerian 330kV power system network with the major area of concentration being the system response during the occurrence of a 3-phase fault. The power network was modeled in PSAT and the fault was introduced to the geregu substation (bus 33). The continual power analysis was performed in the power system network to obtain the optimal location for the installation of the FACTS and the location obtained which was the weakest bus was at bus 21. Hence, SVC and STASTCOMFACTS were installed and simulated one after another. The results obtained showed that the introduced of the FACTS devices were able to damp the high oscillations in the systems which was caused by the three phase fault. (Gu, Qiu, Shu, Zhang, Xiao & Chen, 2023; Nkan, Okoro, Awah & Akuru, 2019) established a circuit capacitive wireless power transfer (CPT) power system network and presented a primary side control strategy for the purpose of achieving a stable power output and ensure consistent high power transfer capability efficiency based on the parity time symmetric theory. The outcome of the results presented showed that the power transfer capability effect was more when the insertion depth of the system coupler array changes from 60 mm to 180mm with the proposed prototype of the CPT being stable at almost 25W with the transfer efficiency generated at 88% which the effectiveness of the chosen model design. (Lu, 2020; Nkan, Okpo & Okoro, 2020) utilized wireless power repeater for multiple loads applications and long distance transmission lines to ensure balance in power from the generation station to the load station. The repeaters performed as power relay that receives and transmits power and also ensures power availability to the load stations. The author focused on carrying out designs of the wireless repeater that would improve the power transfer capability of the power system network. (Wang, Zhou, Guo & Sun, 2022; Nkan, Okpo, Akuru & Okoro, 2020) proposed the utilization of deep learning models for the improvement of the total transfer capability of the power system network by clustering the operating systems into simpler spaces with a two stage cluster system and then utilized a deep learning model for the power transfer improvement. The variable sensibility of the deep learning model was controlled with first order control variable and quasi steady state system was utilized in determining the effects of the inputs to the deep learning model on the IEEE 39-bus network and the outcome of the study showed that the proposed method improved the total power transfer of the power system network. The authors in (Abramov & Peretz, 2020; Natala, Nkan, Okoro & Obi, 2023) utilized an adaptive multi-loop controller system carry the power transfer capacity improvement of the capacitive wireless power transfer systems. The proposed controller comprises of continuous frequency tracking and the tuning of matching network with the aim of regulating the current and real power variables which were considered the main target to power transfer capability improvement. The resulted showed that the proposed system was effective in improving the power transfer of the power system when tested on a 5-bus network. (Luo, Hu, Munir, Zhu, Mai & He, 2022; Nkan, Okpo & Inyang, 2023) utilized a compensation design method in achieving a maximum amount of power transfer with voltage coupling constraints. The input and the output voltages of the power system were maintained at a 90^o phase shift with the aid of derived compensation topologies. The result presented showed that the proposed design had a good performance in improving the level of power transfer in the power system network. The authors in (Nkan, Okpo & Okpura, 2023) proposed a sensitive based method in estimating the level of power improvement with the introduction of FACTS to the power system network and the impact of improved power transfer capability in the market via marginal cost determination. The reliability of utilizing FACTS in the power transfer improvement in the power system network was the major of the determination of the electricity distribution marginal cost and also the impedance adjustments it presents.

III. MATERIALS AND METHOD

The information for the 28-bus network of the Nigerian 330kV transmission system obtained is shown in Fig.1.

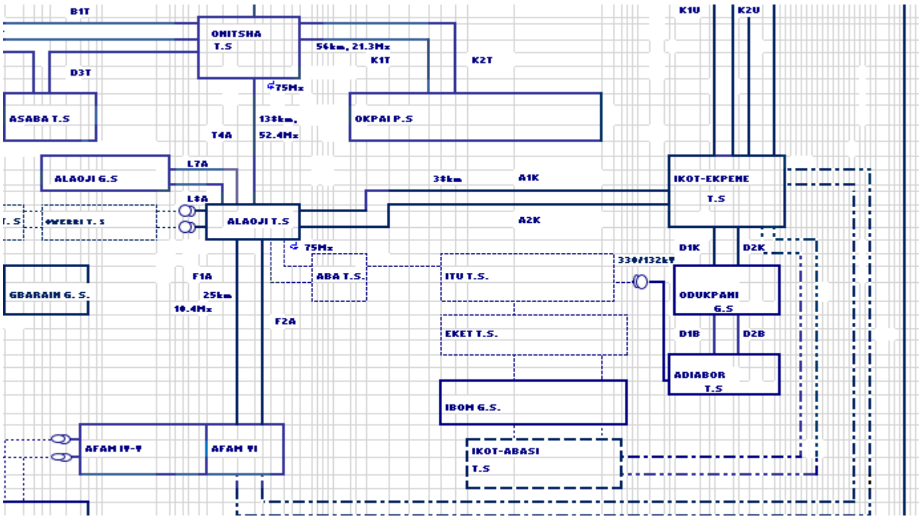

Fig.1. Nigerian 330kV transmission network

The network information provided in figure 1 were mainly situated in the southern region of Nigeria at voltage rating of 330kV. The network comprises of 28 buses with 36 transmission lines. The procedure for modeling the network in NEPLAN is summarized in the flow diagram shown in Fig.2.

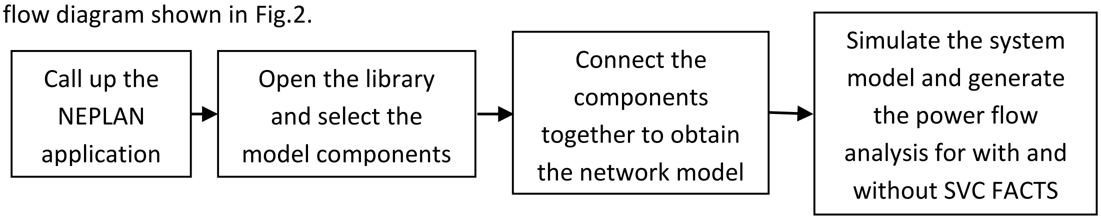

Fig.2. Block diagram of the pattern of modeling in NEPLAN

The NEPLAN had been installed in the desktop and called up. The system contains library for the modeling of the data shown in figure 1. The NEPLAN library was sectionalized to one port, two port, three port and four port model blocks. The main models blocks used for the assembling of the power system model were bus network, load line, bus and transmission line with symbol of load and generation stations. The NEPLAN model of the power system network is shown in Fig.3.

The bus station selected as the reference bus is Afam generation station. Choice of the station is due to the dynamic station with robust power generation capacity. The power system network was simulated to obtain the power flow analysis and the ATC of the network. Then a relation between the ATC and the summation of the distance of the transmission lines was generated with the linear model schematic shown in equation 1.

$$ATC = q_0 + q_1 D + q_2 D^2 + \cdots + q_n D^n \qquad (1)$$

where D represents the distance of the transmission line and $q_0 \ldots . q_n$ represents the coefficient of the polynomial model that is determined using least square method. The model order was extended based on the R-square value obtained. The flow chart of determining the best polynomial order is shown in Fig.4.

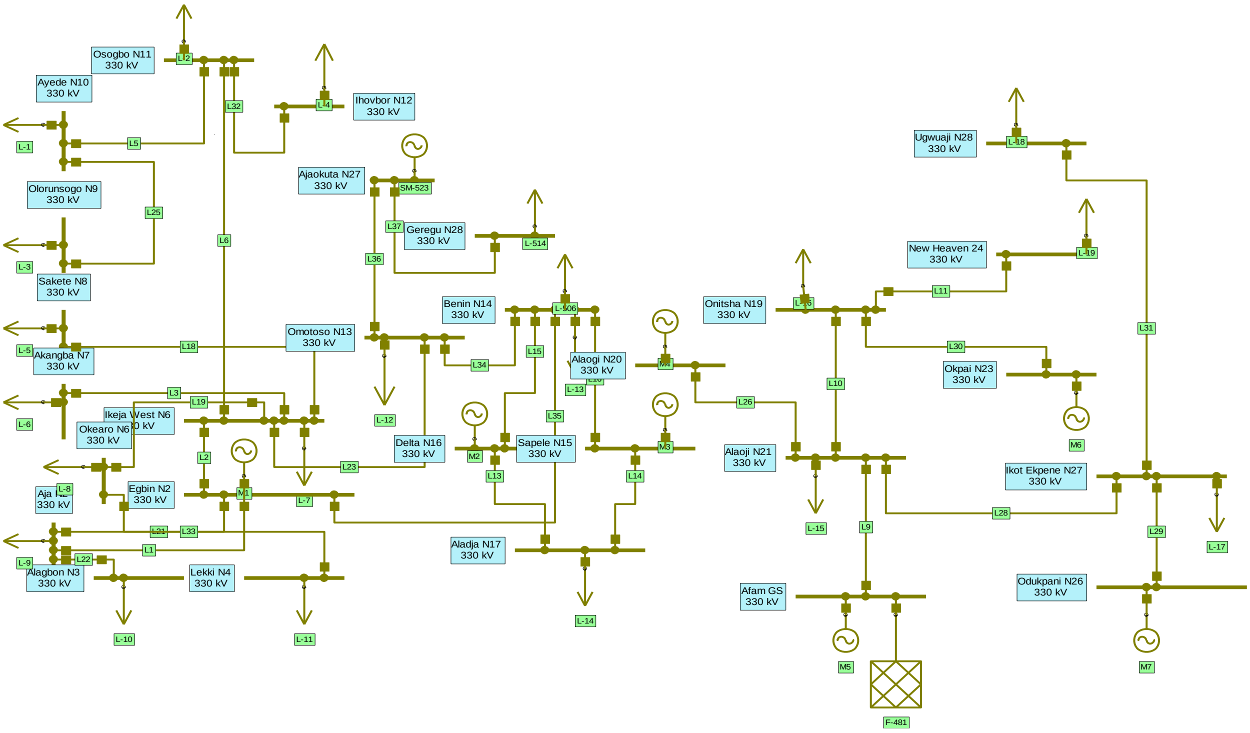

Fig.3. NEPLAN model of the power system

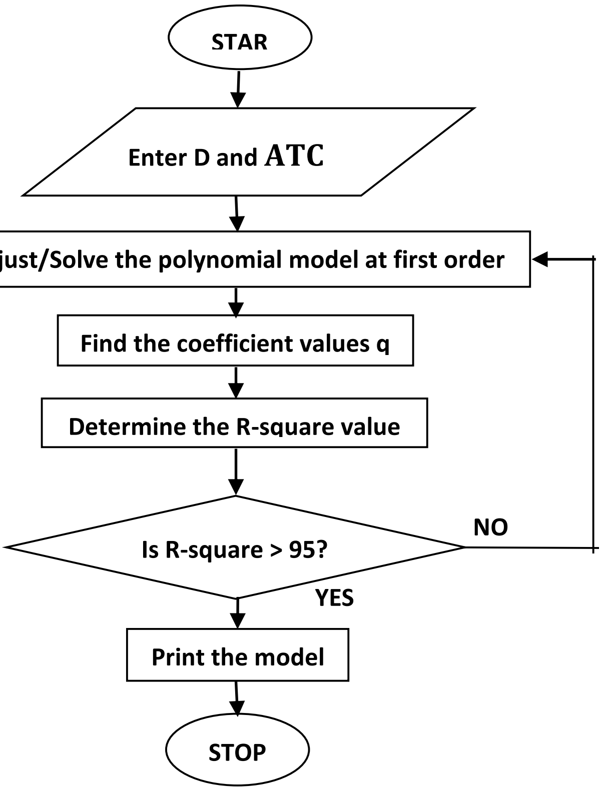

Fig.4. Flow chart of the polynomial model

From the flow chart in figure 4, the polynomial with the R-square value of 95% and above is selected and sent to the genetic algorithm for the determination of the optimal location for the installation of the FACTS.

IV. RESULTS AND DISCUSSION

The plot for the real and apparent power of the power system network without SVC FACTS controller is shown in Fig.5. Most of the transmission lines has real power losses more than 0.03MW and the reactive power losses recorded in some of the transmission lines were more than 0.04MVar. The losses recorded affected the level of power transfer because high power losses shows that the power transfer is low as shown in Fig.6.

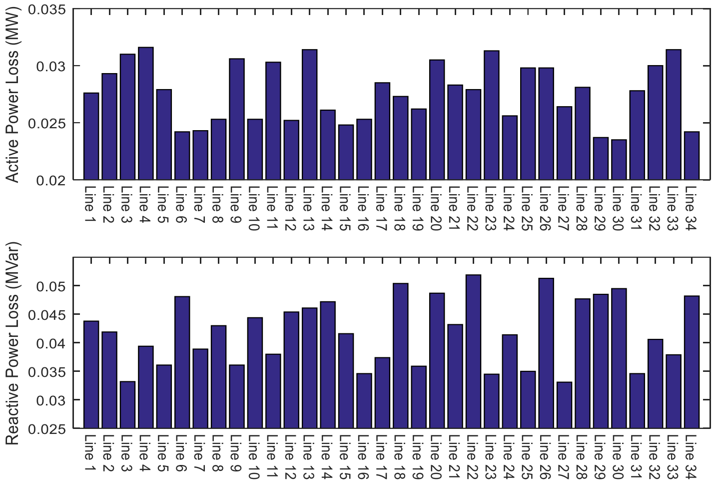

Fig.5. Real and reactive power losses without SVC controller

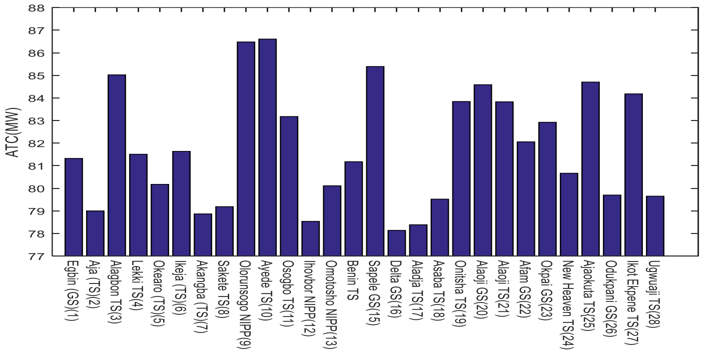

Fig.6. ATC without SVC contrller

From Fig.6, it can be seen that the available transfer capacity is low due to high active and reactive power losses. Based on this, it can be seen that there exist high power congestion level on the power transmission system which would require power enhancement as the highest ATC is 86.4MW. The outcome of the ATC without FACTS controller implemented in the model in equation 1 to determine the best model for the optimal placement of SVC with the results is presented in Table 1.

Table 1. Polynomial model order With the prediction accuracy

Polynomial model order	R-square value
1	0.7723
2	0.8713
3	0.9133
4	0.9517
5	0.9817
6	0.9862
7	0.9908

Based on the accuracy in Table 1, the best polynomial order to be optimized with genetic algorithm is the seventh order, and the outcome of the genetic algorithm ATC of 74.31MW at summative distance of 954.5km which lies on line 8 with SVC placed at Oshogbo transmission station. The real and reactive power losses with the introduction of SVC controller is shown in Fig.7. It can be seen that the introduction SVC reduced the power losses to a maximum of 0.019MW for active power and 0.032MVar for the reactive power. Hence, the losses were minimized with the introduction of SVC FACTS controller. The ATC of the transmission system with SVC FACTS controller is shown in Fig.8. There is an improvement with the introduction of SVC as the highest ATC improvement recorded is 90MW. A comparative analysis of the ATC for the system without and with SVC controller is shown in figure 9.

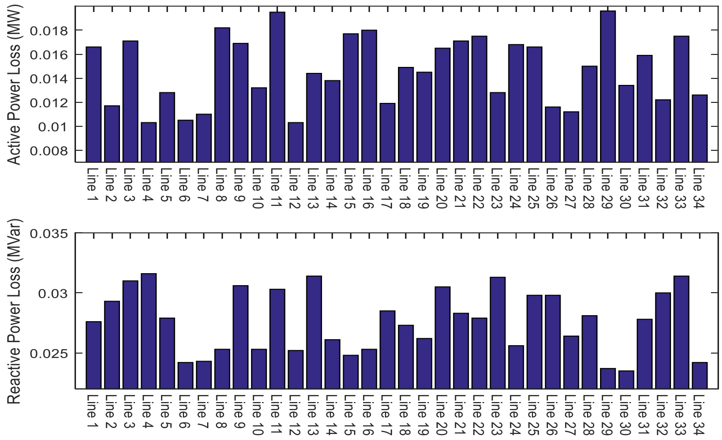

Fig.7. Power losses with SVC FACTS controller

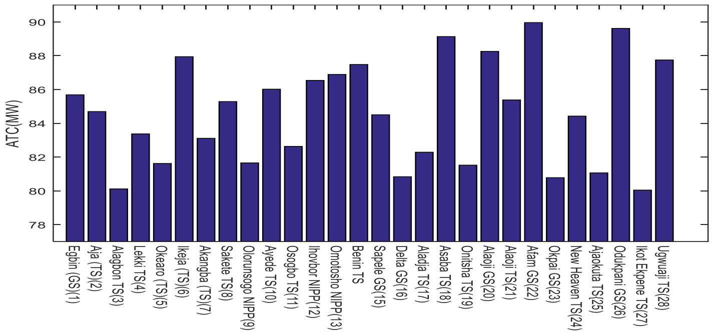

Fig.8. ATC of the transmission power system with SVC

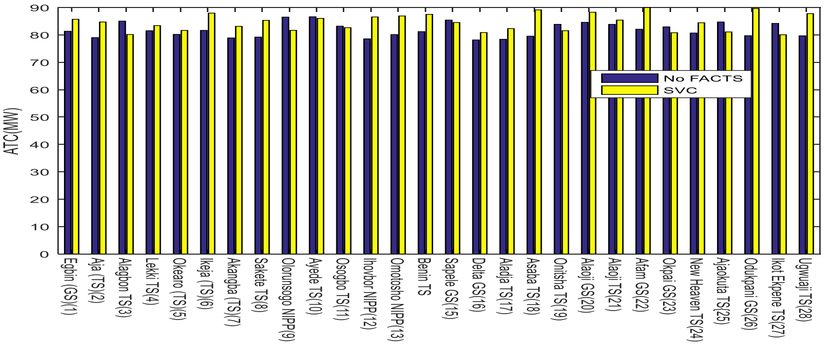

Fig.9. ATC without and with SVC controller

V. CONCLUSIONS

The increase in load demand and power losses has reduced the power transfer of the transmission system. The issue of load demand increases overtime but the power losses is minimized and load congestion reduced to improve the ATC of the power system network. The introduction of SVC FACTS controller reduced the reactive power losses by 32%, real power losses by 36%, and improved on the ATC by 18%. Hence, the results suggest that SVC should be utilized in improving the ATC of the power system network.

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