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Improvement of Power Transfer Capability of the Nigerian National Grid With SVC and TCSC FACTS Controllers

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ABSTRACT : *The Nigeria power transmission network has constantly recorded increase in demand to increase in power flow congestion leading to drastic reduction in power transfer capability in transmission and distribution lines. This issues led to determination of methods and avenues of improving the power flow which resulted to the improvement of the available transfer capability. In this paper, the Nigerian 330 kV transmission network was modeled using NEPLAN software where static Var compensator (SVC) and thyristor controlled series capacitor (TCSC) flexible alternating current transmission system (FACTS) controllers were deployed to improve the power flow and the available transfer capability. The Optimal location for the implementation of the FACTS controllers was determined using genetic algorithm (GA) optimization technique based on the linear regression relationship between the available transfer capability and the summation of the transmission line distance. Comparative analysis was performed between the modeled power system network without FACTS and the power system network with SVC and TCSC. From the results presented, the optimal location obtained for the placement of FACTS was the transmission line between Benin transmission station (TS) and Osogbo TS hence the TCSC was placed on the transmission line and SVC was placed at Osogbo TS which was the closest location of the optimal distance located.*
KEYWORDS: a*vailable transfer capability, FACTS, optimal location, SVC, TCSC.*

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I. INTRODUCTION

The available transfer capability (ATC) has been a factor used to determine the amount of power that is transmitted to load stations from generation stations [1, 2]. In the study of the Nigeria power systems by [3, 4, 5], it was found that the constant epileptic power supply recorded in power transmission systems in Nigeria was largely due to the rise in power congestion in the power flow of the transmission and distribution lines. The reduction in available transfer capability also affected the durability, stability, economic stability and power transmission stability of the systems in Nigeria [6, 7]. In curbing these issues, the paper proposed the use of shunt and series flexible alternating current transmission system (FACTS) controllers for the improvement of the availability transfer capability of the power system network. The improvement of the available transfer capability would reduce the rate of epileptic power supply and improve on the existing power congestion in the transmission and distribution networks. However, several procedures were required in the improvement of the available transfer capability of which the most essential was the optimal FACTS location [8, 9, 10] with particle swarm optimization technique which involves development of the relationship between the distance and the available transfer capability. The data utilized in this paper is a real time network obtained from the Nigerian Control center (NCC) Oshogbo. The power system network was modeled in NEPLAN with the power flow analysis performed and obtained and same was done for the available transfer capability. The thyristor controlled series capacitor (TCSC) and the static Var compensator (SVC) FACTS controllers were placed according to the optimal location obtained from the genetic algorithm optimization performed. The power flow analysis and the available transfer capability for the system without and with FACTS controllers are analyzed and compared to determine the best FACTS device that improves the available transfer capability and reduces the power congestion on transmission lines.

II. REVIEW OF RELATED LITERATURE

The application of flexible alternating current transmission system (FACTS) controllers to enhance transient stability using the Nigerian 48-bus power system network was carried out in [11, 12, 13]. Two different FACTS devices were deployed namely SVC and static compensator (STATCOM) where power system analysis toolbox (PSAT), a commercially available power system toolbox in MATLAB was used to model the Nigerian power system network having fault introduced at Geregu substation located at bus 33 and the two FACTS devices separately placed at bus 21(Jos transmission station). The outcome showed a high level of stability on voltage and power. The determination of the available transfer capability with FACTS devices was done using the power loss sensitivity index method for optimal location of FACTS devices. This was achieved through the combination of two TCSC, two thyristor controlled phase angle regulator (TCPAR) and TCSC with TCPAR). The simulation was done in IEEE-9bus network in PowerWorld 8.0. The study failed to determine the percentage ATC improvement with the installation of FACTS [14, 15, 16]. The study to determine the available transfer capability (ATC) of an IEEE 30 bus power system network with interline power flow controller (IPFC) using the particle swarm optimization (PSO) to obtain the optimal IPFC settings was carried out in [17, 18, 19]. MATLAB version 7.10. 0 was deployed to run the simulation, the outcome showed a good improvement of ATC with the introduction of IPFC. The optimal location of IPFC was not done with any optimal tool and the ATC improvement was minimal. Boosting of ATC in IEEE 30 bus and 6 bus sample using the PSO tool on the optimal settings of the TCSC for the enhancement of the ATC of the network was studied in [20, 21]. The outcome showed an increment in ATC in the power system network. The optimal placement of TCSC was not done as such the improvement of ATC may not be of optimal outcome. The study to determine ATC on transmission lines to improve the outcome using TCSC on an IEEE 24-bus network was carried out in [22, 23]. The ATC was determined with repeated power flow (RPF). the paper failed to carry out optimal FACTS placement of the TCSC with any optimization tool. The IEEE 30 bus network model base on different TCSC placement methods which includes line reactance, power transfer distribution factor, line thermal limitation and least bus voltage magnitude was carried out in [24, 25] to determine the ATC, the outcome gave an ATC increment between 2% to 85% at various placement methods and real power loss achieved were up to 25%.

The study carried out in [26, 27] used PSO in the estimation of the optimal settings of TCSC device for the enhancement of ATC on power system network. The work failed to determine the optimal placement of the FACTS for the ATC improvement of the power system network. The optimal enhancement of ATC improvement of the IEEE 30 bus network using TCSC to determine the optimal location of the TCSC in the power system network using genetic algorithm optimization tool was discussed in [28, 29]. The outcome of the study which was described as the new approach showed improvement on ATC with the installation of TCSC. The emphasis of this study was the enhancement of ATC with only TCSC. The study failed to perform comparative analysis with another FACTS device. The study in [30, 31], deployed SVC and TCSC FACTS controller models into the Newton Raphson power flow analysis model and simulation was carried out with IEEE 30 bus network in Matlab. 14% ATC improvement were recorded for both the SVC and the TCSC devices. The gap in this study was the absence of optimal location of the FACTS devices. The optimal placement and sizing of TCSC was studied in [32, 33] using genetic algorithm optimization tool. The author used power transfer distribution factor for the determination of the ATC comparing it to the ATC calculated from repeated power flow method. The outcome showed that the use of power transfer computation factor was more reliable in determining the ATC of power system network than the repeated power flow method. This study centered more on the format of calculating ATC and not on improvement of ATC with the FACTS controllers which was the major gap of the research. Studies on ATC enhancement in a 4-bus system network using cascaded based artificial neural network (ANN) model with static synchronous series capacitor (SSSC) FACTS controllers was carried out in [34, 35], it was used to stabilize the constant rise in independent operator system (ISO) and Matlab was used for the simulation. The gap in this study was the absence of optimization technique for the optimal placement of the SSSC. The study in [36, 37] reviewed several ways of determining ATC and other parameters of Power transfer capability and how the ATC can be improved with FACTS in a 14-bus network which the outcome showed that ATC of the power system network was improved. There was absence of optimal placement of the FACTS for further improvement of the ATC in the 14-bus network. The study in [38] compared the outcome of ATC improvement with SSSC and unified power flow controller (UPFC) and also determined the total transfer capability (TTC) with both FACTS in a 30-bus network. The model was simulated with power system analytical toolbox and the outcome showed an improved ATC with both FACTS. The study in [40, 41] determined the power loss by optimally placing STATCOM and IPFC on the IEEE-14 bus system. The outcome showed a reduced power loss in the network. Particle swarm optimization was the technique used in the study. The study in [42, 43] determined how to improve ATC with load flow controllers using the power Injection Model (PIM) and generation shift distribution factors (GSDF). the study failed to utilize optimization technique for optimal placement of the FACTS devices. The study in [44, 45] utilized TCSC in a 30-bus IEEE power system network in maximum the ATC of the system and the outcome showed an improvement. However, there was absence of optimal FACTS placement.

III. MATERIALS AND METHOD

The data utilized in this paper was obtained from the National control center in Osogbo Osun State Nigeria. The data comprises of line diagram of 28 buses of the Southern region of the Nigerian 330 kV transmission network. The power system real time data comprises of 28 buses and 36 transmission lines. The area was mainly 330 kV network that spans from the south western region, south southern region and south eastern region. The NEPLAN model of the network is shown in Figure 1.

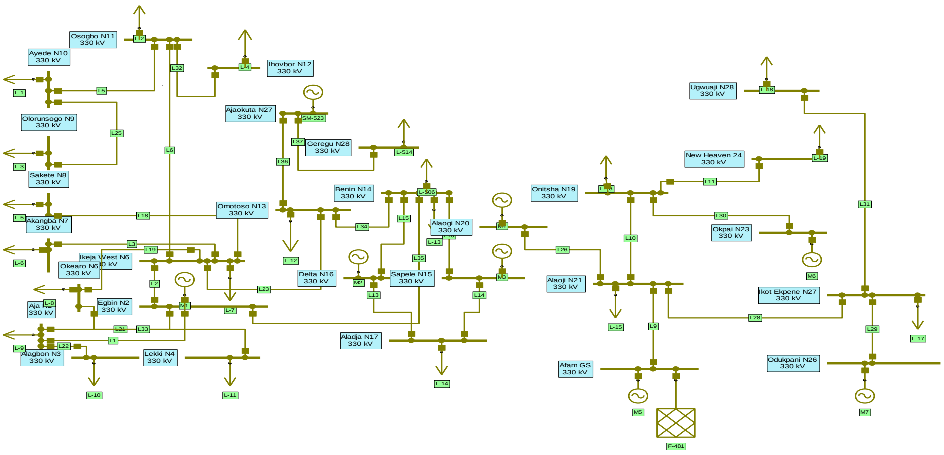

Figure 1: NEPLAN model of the power system network without FACTS controllers

The regression model schematics showing the relationship between the available transfer capability and the distance of the transmission line as obtained from the simulation of the power system model in Figure 2 is given in Equation (1).

$$ATC = \sum_{i=0}^{n} a_{iD_i^n} \quad (1)$$

where D is the distance in km, a represents the coefficient of the distance that was determined with least square method in Matlab. The simulation of the power system network without FACTS in Figure 2 generated the power flow values and the ATC at various distances utilized in the formation of the regression model that was subjected to genetic algorithm to determine the optimum distance. From the ATC and distance values obtained from the power system model in Figure 1, the values were sent to Matlab where the polynomial order was adjusted until an order at error (E) of 0.0001 or less was obtained with the model subjected to genetic algorithm to obtain the optimal distance for FACTS placement. The NEPLAN Models with SVC and TCSC are shown in Figures 2 and 3 respectively.

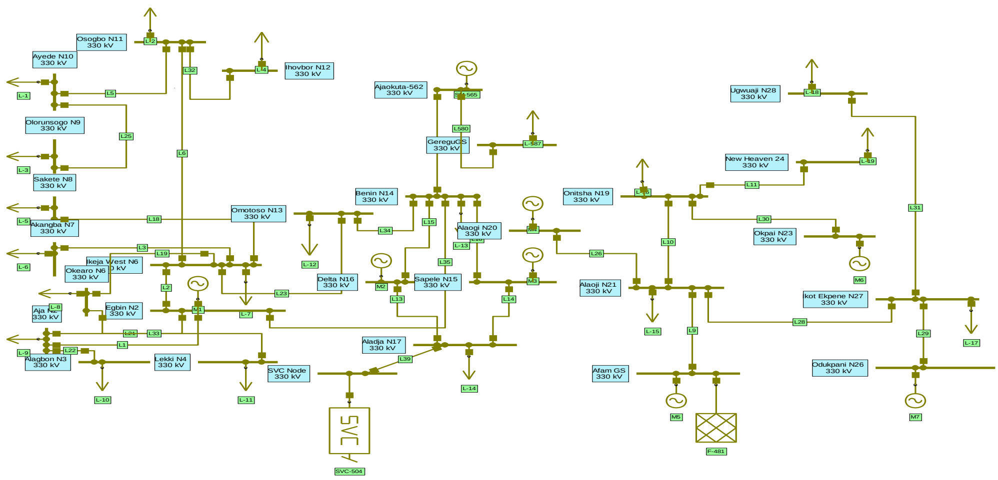

Figure 2: Power system model with SVC in NEPLAN

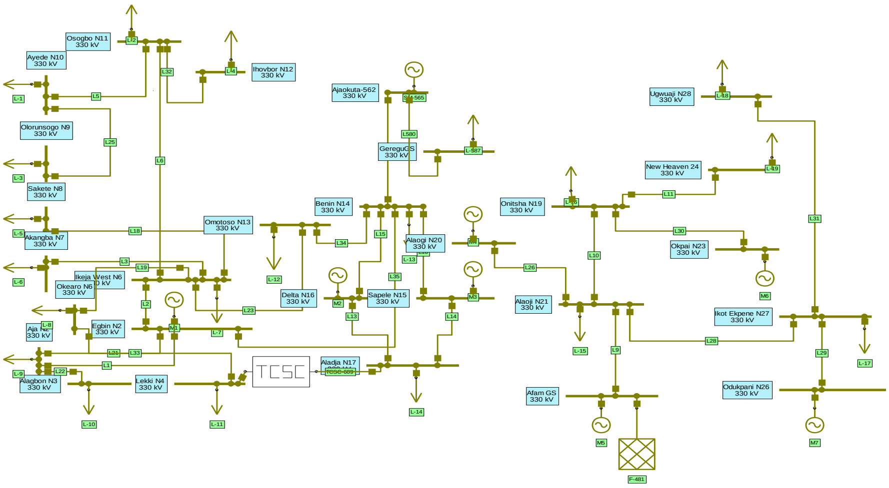

Figure 3: Power system model with TCSC in NEPLAN

IV. RESULTS AND DISCUSSION

Matlab tool is deployed for the determination of the regression polynomial for the relationship between available transfer capability and the line distance and the data utilized for the fitting of the model is shown in Table 1.

Table 1: Data for fitting model

Transmission line distance (km)	ATC (MW)
270	78.8481
521	83.3867
546	82.2383
684	84.2635
746	84.2990
764	83.7468
901	78.3024
1016	78.6193
1018	80.8764
1114	82.7778
1251	83.8900
1283	81.6686
1346	85.3798
1453	84.4652
1503	86.7178
1605	82.7820
1637	80.9263
1651	78.9507
1681	83.4986
1707	85.0092
1734	81.8111
1819	78.8174
1854	80.3982
1867	79.3829
1930	80.5290
1968	81.9608
2040	82.7443
2096	82.1168
2161	85.8783
2412	82.6625
2453	86.4926
2573	83.7394
2783	86.6192

The best fitted model outcome has an error (E) value of 0.000087 at prediction accuracy of 99.08 %. the model is subjected to genetic algorithm and the optimal outcome obtained is ATC of 74.31 MW at distance of 954.5 km. The optimum distance is line 8 between Benin TS and Osogbo TS. Hence the TCSC FACTS controller is placed at the transmission line connecting Benin and Osogbo while the SVC is placed at Osogbo. The ATC of the power system without FACTS is shown in Figure 4.

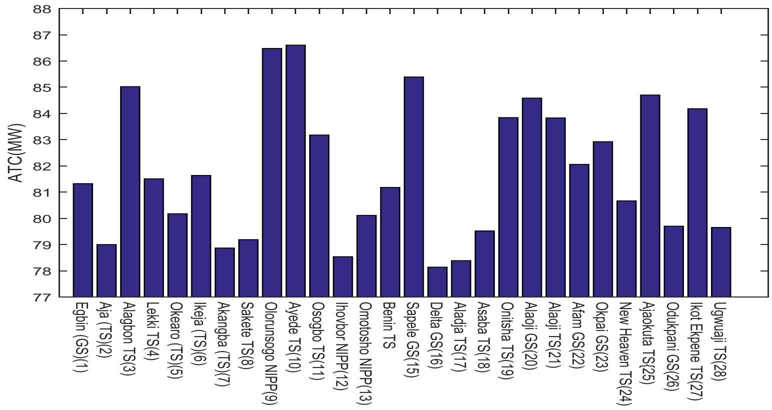

Figure 4: ATC without FACTS in the Southern Nigerian 330 kV power system network

From the barchart of the ATC of the system without FACTS presented in Figure 4, it is observed that the ATC are low in buses 2, 7, 8 12 and 16. This suggest power congestion and a means of power transfer improvement is needed to improve the ATC of the network to ensure that what was sent was received in these networks. The ATC for the power system with SVC FACTS controller is shown in Figure 5.

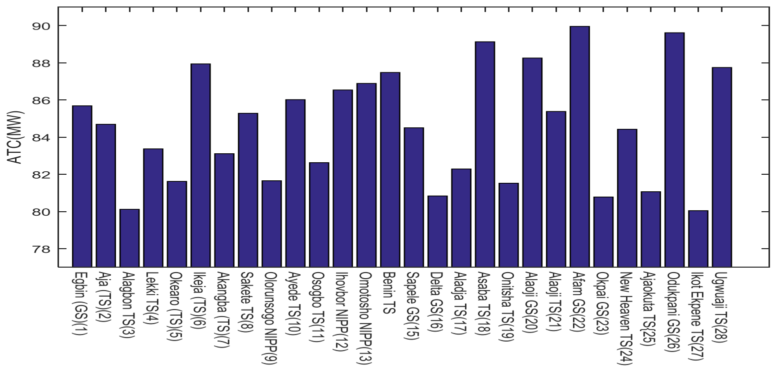

Figure 5: ATC of the power system with SVC FACTS in the Southern Nigerian 330 kV power system network

From Figure 5, There is an improvement with the installation of SVC, but it is observed that the ATC are low in buses 3, 16, 19 23, 25 and 27. Hence, the outcome of ATC with TCSC FACTS is plotted and displayed in Figure 6.

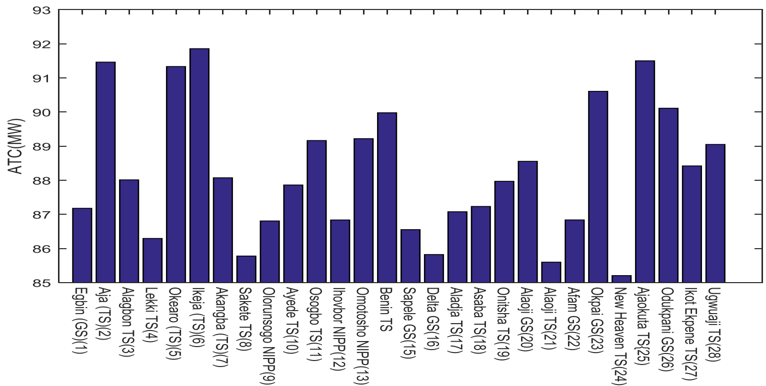

Figure 6:ATC with TCSC FACTS in the Southern Nigerian 330 kV power system network

From Figure 6, it is observed that there are improvements with the installation of TCSC FACTS controller when compared to the ATC outcome of the system without FACTS and with SVC FACTS.

The comparative plot of the ATC without and with FACTS controllers is shown in Figure 7.

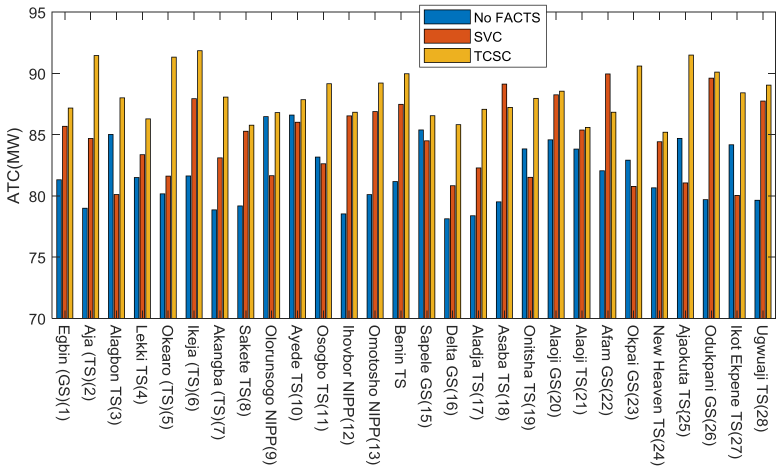

Figure 7: Comparative barchart of the ATC for with and without FACTS controllers

V. CONCLUSION

The major aim in this study was to obtain the optimum placement of TCSC and SVC FACTS for the improvement of the ATC of the southern region of the Nigerian 330 kV transmission network. The power system network was modeled and the power outcome obtained from NEPLAN software. The ATC of the power system without FACTS, with SVC and with TCSC were obtained and presented. Genetic algorithm was used to optimize the obtained polynomial relationship between the ATCs and the transmission line distance. The outcome optimum location identified by genetic algorithm was ATC of 74.31MW at summative distance of 954.5km. The optimum distance was line 8 between Benin TS and Osogbo TS. Hence the TCSC FACTS was placed at the transmission line connecting Benin and Osogbo while the SVC was placed at Osogbo. Results of the simulations of the performances of the FACTS controllers showed that TCSC performed better than SVC. It is therefore very imperative to implement these FACTS controllers in the Nigerian southern 330 kV transmission network to minimize the rate of power congestion and improve the available power transfer capability of the power system network.

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