© FEB 2023 | IRE Journals | Volume 6 Issue 8 | ISSN: 2456-8880

Load Flow Analysis of 132/33KV Power Network for Voltage Enhancement Using Static VAR Compensation (SVC) Technique

W. IKONWA[1], H.N. AMADI[2], B. DIKE[3]
[1, 2, 3] Department of Electrical Engineering, Rivers State University, Port Harcourt, Nigeria

Abstract- The usage of flexible alternating current transmission systems (FACTS) equipment is crucial for improving the power network's parameters. The load flow analysis and voltage profile enhancement of 132/33kV distribution network in Benin City were the main subjects of this study, both with and without the application of the Static Var Compensator (SVC) compensation technology. In order to show the effects of the static var compensator (SVC) on the power network for voltage enhancement, the study employed Electrical Transient Analyzer Program (ETAP) software to model the single line diagram of the network and execute the load flow simulation. The load flow simulation results showed that transformers T1 (116.2%), T2 (110.8%), T3 (191.8%), and T4 (110.5%) were overloaded according to the IEC standard that states that the constructive lifespan of the equipment will be shortened by continuous loading of the oil-immersed transformers above the limit of 80%.Bus 5 was observed to be the most overloaded bus. SVC of 150 MVAR was installed at the weak buses for reactive power compensation and the transformers upgraded to 75MVA, the load flow analysis results showed that the voltage profile improved significantly and there was reduction in the overloading of the transformers; T1 (78.5%), T2 (75%), T3 (61.5%), and T4 (74.8%), to increase the life span of the transformers.

Indexed Terms- ETAP, load flow analysis, SVC, Thyristor

I. INTRODUCTION

Increased power consumption brought on by an increasing population has complicated network connections, led to voltage instability, power security concerns, total blackouts, a lack of reactive power, and substantial long-distance transmission losses [1][2]. This is due to the fact that line congestion pushes the performance of the power system network near to its limit. The performance of the transmission systems would have been enhanced by expanding the transmission network, but this is not feasible due to financial, environmental, and health considerations [3, 4].

As a result, in order to enhance the performance of the alternating current power system, power electronic devices are needed to regulate both active and reactive powers as well as to increase the usable capacity of the current transmission system [5]. The use of an electrical system with a fast response time known as a flexible alternating current transmission system is a key strategy for combating the underwhelming performance of the transmission network (FACTS) [6]. One of such FACTS devices for combating the underwhelming performance of the transmission network is Static Var Compensator (SVC). The term SVC refers to a shunt-connected FACTS device that has an adjustable output and can exchange capacitive or inductive currents with the connected system. Certain electrical power system parameters, typically bus voltage, are controlled by this current [7].

II. REVIEW OF PREVIOUS WORKS

In contrast to SVC models reported in the open literature, [8] proposed two comprehensive SVC models: total susceptance model and firing angle model, suited for conventional and optimum power flow analysis. The suggested models use the variable shunt susceptance concept rather than the generator concept often used for the SVC representation. He put these models to the test on a real power network that had 128 transformers, 166 buses, 108 transmission lines, and 26 generators.

According to [9], It is challenging to expand the transmission system's capacity by adding more lines or changing the voltage level in order to keep up with the continuously increasing electricity demand. Power flow controllers that can increase the capacity of the current transmission line and regulate power flows in designated transmission corridors are therefore becoming more and more necessary. Due to this, a new class of controllers known as the Flexible AC Transmission System has arisen in recent years (FACTS). Using the IEEE 5-bus power system as a test example, they looked into the benefits of FACTS devices for power flow operation in their research. The results showed that the FACTS controllers improved voltage stability and increased the capacity of the current transmission line.

For the purpose of determining the best location and size of SVC, a new swarm-based Firefly Algorithm has been introduced, and a sensitivity analysis-based voltage collapse proximity indicator has been presented in [10]. It has been proven and tested that FA is effective. The findings demonstrate that implementing SVC can lower the overall active power losses and enhance the voltage profile of the IEEE 14 bus and IEEE 30 bus systems used as a test case.

To investigate the impact of two Flexible AC Transmission System (FACTS) controllers namely: static Var Compensators (SVC) and Thyristor Controlled Series Capacitors (TCSC), on voltage collapse in power systems, detailed steady-state models with controls of these two FACTS controllers were presented in [11]. The use of the models and methodologies suggested in this paper was demonstrated using the European system as a test case.

Comprehensive steady-state models with a tool for locating SVC (Static Var Compensators) and other shunt compensation devices for voltage support based on the identification of critical modes was presented in [12]. By examining the system modes close to the point of collapse, critical modes are calculated in this research. The best locations for system reinforcement are chosen based on system participation parameters for the critical mode. By evaluating the effects of the addition of svc, the proposed method was evaluated using BC Hydro 1380 bus model as test system.

[13] examined how svc affects a power system's voltage stability. IEEE-9 bus system was employed as a test case in this paper, which was modeled using the power world simulator software. The load flow solution was computed using the Newton-Raphson method, reactive power was added to the svc, and the impact of the svc on the IEEE-9 bus system was investigated. According to the simulation results, the voltage increased when Q was introduced into the svc circuit.

To reduce losses, reactive power generation, and network voltage profile were the main focus of [14]. The load flow in various situations was first estimated using the Newton-Raphson method, and then the optimization capacity was calculated using the optimized Reduced Gradient power flow method. The IEEE 57 bus was selected as a test case in the study, and it was modelled and simulated using Matlab software both with and without the usage of SVC. The findings demonstrated that the Generalized Reduced Gradient optimization power flow (GRG-OPF) approach significantly enhanced the voltage profile, produced simulation results quickly, and minimized active/reactive power losses when SVC reactive power was included as a variant into the GRG-OPF technique.

The SVC is just one of numerous FACTS components that are linked in parallel to the distribution network nodes and serve as injection or absorption sources of static reactive power. A parallel design of switches, controlled inductors, thyristor valves, and capacitor banks make up the SVC. It functions similarly to a variable parallel reactance that may be made into a highly responsive device by altering the firing angle of the thyristors[15].

Most of the literatures reviewed in this paper are concerned with optimal placement of SVC, voltage profile improvement and reduction of power losses using SVC and used test systems such as IEEE test systems, European test system, BC Hydro 1380 bus model, to investigate the effect of SVC. The reviewed papers used Matlab or Power World Simulator software to model the test system. However, this present study focuses on the Nigerian network; 132/33kV substation in Benin city, as test case to investigate the impact of SVC for voltage profile improvement and power loss reduction, using ETAP software to model the single line diagram and run simulations. The result will help in recommending size and location of SVC in the substation thus help to improve the stability of national grid.

III. MATERIALS AND METHODS

- Modeling of Static Var Compensator (SVC)

This study employs a VAR compensator of the Thyristor-Controlled Reactor Fixed Capacitor (TCR-FC) type, whose equivalent circuit layout is depicted in figure 1. By controlling the reactor current with a thyristor, this configuration offers continuously controllable lagging to leading VARs. Two or more capacitor banks are used to regulate the leading VAARs. The TCR is typically rated higher than the total fixed capacitance in order to provide net lagging VARs as well. By adjusting the firing angles of back-to-back pairs of thyristor connected in series with the reactor, it is possible to change the current flowing through it.

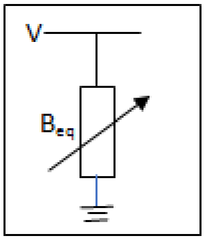

Fig. 1: Circuit model of SVC

A SVC equivalent circuit is shown in Figure 1. The following can be used to express the equivalent reactance to a control inductor via a thyristor:

$$X_L = \frac{\pi X_L}{2(\pi-\alpha)+\sin(2\alpha)} \qquad (1)$$

You may determine the parallel configuration of thyristor-controlled inductors and capacitors' SVC equivalent reactance by:

$$X_{Leq} = \frac{\pi X c X_L}{X_c(2(\pi-\alpha)+\sin(2\alpha))-\pi X_L} \qquad (2)$$

The firing angle of the thyristors is indicated by α, and Xc represents the parallel capacitor reactance. Taking into account SVC equivalent susceptance, which is a result of the thyristors' firing angle, as shown in (3):

$$B_{eq} = \frac{\pi X_L - X_c(2(\pi-\alpha)+\sin(2\alpha))}{\pi X_c X_L} \qquad (3)$$

The firing angle of the thyristors is a constant function of the susceptance of SVC, unlike the capacitor, according to (3) [16].

Calculation of SVC's injection or absorption of reactive power is done using (4):

$$Q_{SVC} = -V^2 B_{eq} \qquad (4)$$

Where V is the node voltage that the SVC is coupled to.

- Substation Modelling

The study case is 132/33 kV Substation in Benin City, consisting of four (4) number power transformers of 132/33kV which are $1x30MVA\ and\ 3x60MVA$ consisting of 12 feeders. The distribution network single line diagram was modelled using ETAP 19.0 software and the simulation was done using the load flow and short circuit analysis tool embedded in the ETAP 19.0 software.

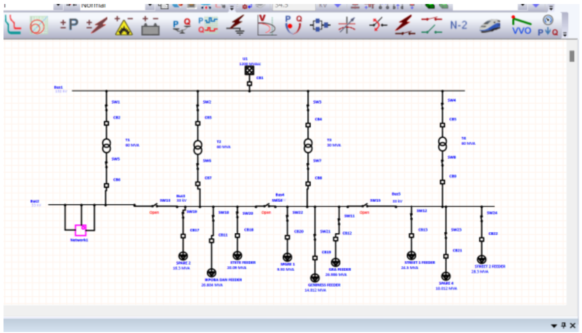

Fig. 2: The Single Line Diagram of 132/33kV Substation in Benin City

IV. RESULTS AND DISCUSSION

- Load flow analysis without compensation

A load flow analysis (LFA) of the 132/33kV network was done using Newton-Raphson power flow solution numerical technique embedded in the ETAP 19.0 software. At this stage, the LFA was done without any involvement of the FACTS device (SVC) and implemented to investigate the substation equipment loadings. The results are presented in Tables I and II. From the load flow results, it is clear that the 132/33kV substation in Benin city is experiencing setbacks, such as a poor voltage profile and the transformers are heavily loaded. Table I shows the condition of the transformers after the LFA and it indicates that the transformers are overloaded in terms of the power system regulation as stated in the provisions of the IEC standard 60354 [17]. According to the IEC standard, constant loading of the oil-immersed transformers above the limit of 80% will result in reducing the constructive lifespan of the equipment. The results show that transformers T1, T2, T3, and T4 are overloaded.

Table I. Transformer Load flow analysis result – without compensation

Equipment	Ratings	% Power Factor	% Loading	kW Flow	kvar Flow	kW Losses	Amp Flow
T1	60 MVA (132/33)kV	79.55	116.2	54350.8	43668.7	175.1	304.9
T2	60 MVA (132/33)kV	79.81	110.8	52059	41341	159.5	290.8
T3	30 MVA (132/33)kV	80.83	191.8	41817.5	39515.1	105.7	251.6
T4	60 MVA (132/33)kV	79.83	110.5	51913.3	41194.8	158.5	289.9

Table II. Bus bars Load flow analysis result – without compensation

Equipment	Rated value (kV)	Operating Voltage (%)
Bus 1	132	100
Bus 2	33	91.33
Bus 3	33	91.77
Bus 4	33	84.88
Bus 5	33	91.8

Table II shows the Load flow analysis results of the bus bars. The provisions of the IEC standard indicate a ±6% tolerance for voltage drop. As observed from the table, all the buses violated the voltage drop limit and Bus 5 is observed to be the most overloaded bus in the network.

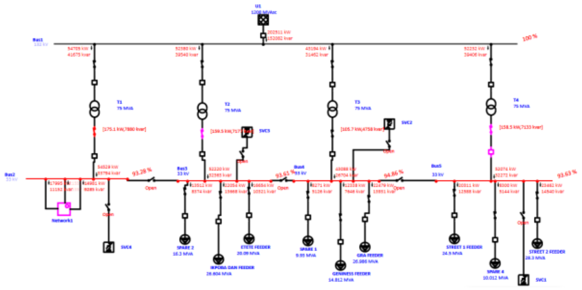

Fig. 3: LFA of the 132/33kV network without SVC

- Load Flow Analysis – With SVC and transformer upgrade to 75MVA

SVC of 150 MVAR was installed at the weak buses for reactive power compensation and the transformers upgraded to 75MVA. Tables 3 and 4 present the LFA results for the transformers and buses after transformer upgrade and the reactive power compensation using SVC was done.

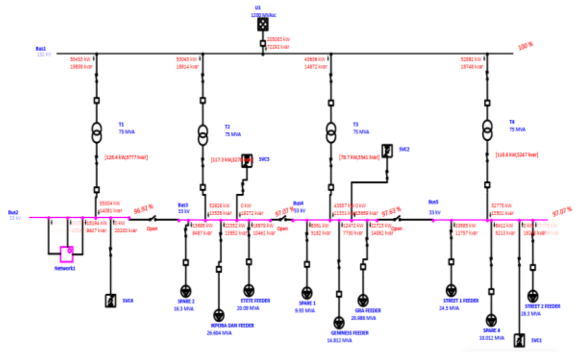

Fig. 4: LFA of 132/33kV network with SVC and transformer upgrade to 75MVA

Table III: LFA results With SVC and transformer upgrade to 75MVA

Equipment	Ratings	% Power Factor	% Loading	kW Flow	kvar Flow	Amp Flow	kW losses
T1	75 MVA (132/33)kV	94.14	78.5	55432.6	19858.5	257.5	128.4
T2	75 MVA (132/33)kV	94.25	75	53043.5	18813.8	246.2	117.3
T3	75 MVA (132/33)kV	94.65	61.5	43635.5	14872.2	201.6	78.69
T4	75 MVA (132/33)kV	94.25	74.8	52891.8	18747.9	245.4	116.6

Table IV: Load flow analysis results of the bus bars – with SVC and transformer upgrade to 75MVA

Equipment	Rated value (kV)	Operating Voltage (%)
Bus 1	132	100
Bus 2	33	96.92
Bus 3	33	97.07
Bus 4	33	97.63
Bus 5	33	97.07

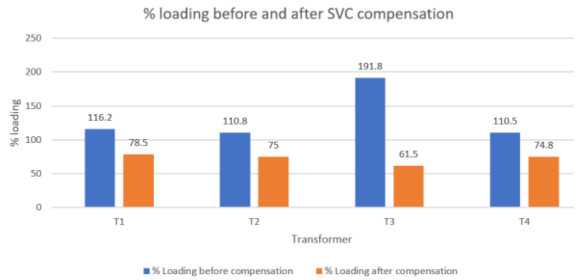

Fig 5: % Loading before and after SVC compensation and transformer upgrade

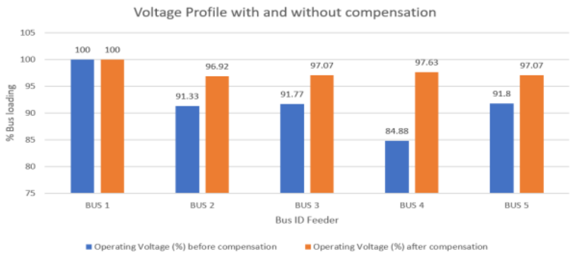

Fig 6: Voltage profile with and without compensation

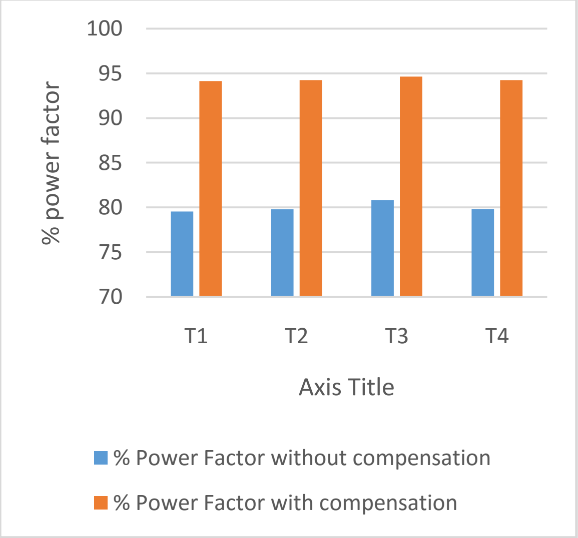

Fig. 7: Power Factor with and without compensation

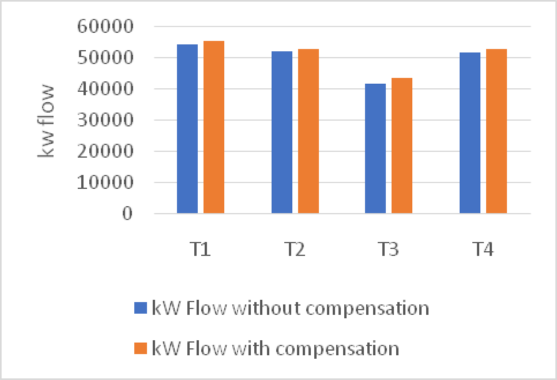

Fig. 8: kW flow with and without compensation

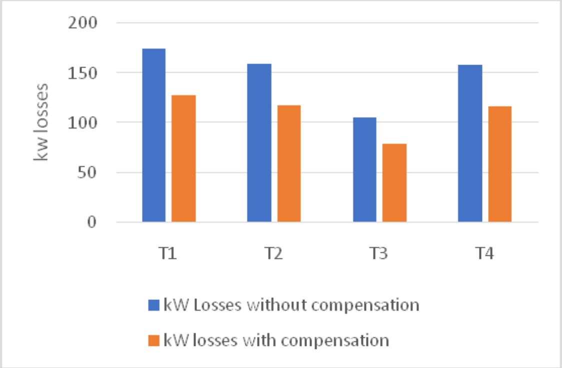

Fig. 9: kW losses with and without compensation

The charts in figures 5 -9 show clearly some significant level of improvement in the % loading of the transformers, voltage profile, % power factor, kW flow and kW losses, when the transformers were upgraded to 75MVA and SVC connected to the network at the weak buses.

CONCLUSION

Through the use of load flow analysis (LFA), futuristic planning and effective operation of the current power system are made possible. ETAP 19.0 software was used in this study to model the 132/33kV network for the load flow analyses. The software's built-in Newton-Raphson numerical approach was utilized to carry out the load flow simulation. The overloaded transformers and weak buses were evident in the findings. Reactive power losses were compensated using the SVC approach, which also improved the voltage profile. The overloaded transformers' percentage loadings were reduced to a level below what was required by IEC standard 60354, which says that continuous loading of the oil-immersed transformers above the limit of 80% will shorten the equipment's useful lifespan.

REFERENCES

[1] T.R. Ayodele, A.S. Ogunjuyigbe, and O. Oladele - Improving the TransientStability of Nigerian 330 kV TransmissionNetwork Using Static Var Compensation- Part 1: The Base Study, Nigerian Journal of Technology, vol 35, no 1, pp. 155 – 166, 2016.

[2] K.O. Oyedoja - Modeling and Simulation Study of the Use of Static Var Compensator (SVC) for Voltage Control in Nigeria Transmission Network, International Journal of Engineering and Applied Sciences, vol5 no. 5, pp. 44-50, 2014.

[3] S. Rahimzadeh and M. T. Bina - Looking for Optimal Number and Placement of FACTS Devices to Manage the Transmission Congestion, Energy Conversion and Management, vol. 52, pp. 437 – 446, August 2011.

[4] M.E. El-Hawary, Introduction to Electric Power Systems, 2nd Ed.: John Wiley and Son Incorporated Publishers, pp. 315, 2008.

[5] M. Karthikeyan and P. Ajay-D-Vimalraj - Optimal Location of Shunt FACTS Devices for Power Flow Control, in proceedings of *IEEE* 2011, International Conference on Emerging Trends in Electrical and Computer Technology ICETECT,Negercoil, India 2011, pp. 154 – 159.

[6] M.O. Ganiyu and T.M. Adekilekun - Unified Power Flow Controller Applications In Interconnected Power System: a case study of Nigerian transmission system, in proceedings of the *IEEE* 14th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering, STAT2013, Sousse, Tunisia, 2013, pp. 499 – 507.

[7] T.R. Ayodele, A.S. Ogunjuyigbe, and O. Oladele - Improving the Transient Stability of Nigerian 330 kV Transmission Network Using Static Var Compensation- Part 1: The Base Study, Nigerian Journal of Technology, vol 35, no 1, pp. 155 – 166, 2016.

[8] H. Ambriz-Perez, E. Acha, C.R. Fuerte-Esquivel - Advanced SVC models for Newton-Raphson Load Flow and Newton Optimal Power Flow Studies, Power Systems, *IEEE* Transactions, March, 2000.

[9] H. Bakir, A. Ozturk, S. Tosun - Investigation of Power Flow Effect of Serial and Parallel FACTS Devices, vol 6, pp. 6-11, 2018.

[10] B. Venkateswara Rao and G.V. Nagesh Kumar,"Sensitivity Analysis based Optimal Location and Tuning of Static VAR Compensator using Firefly Algorithm",Indian Journal of Science and Technology, Vol 7(8), pp. 1201-1210, 2014

[11] C.A. Canizares, Z.T. Faur - Analysis of SVC and TCSC Controllers in Voltage Collapse, *IEEE* transactions on power systems, vol 14, Issue 1, pp. 158-165, 1999.

[12] Y. Mansour, W. Xu, F. Alvarado, and C. Rinzin - SVC Placement Using Critical Modes of Voltage Stability, *IEEE* transactions on Power Systems, vol. 9, Issue 2, pp. 757-763, 1994.

[13] N.A.B. Mat Le, W. Musa, and N.A. Salim - The Modeling Of Svc For The Voltage Control In Power System, Indonesian Journal of Engineering and Computer Science, vol 6, issue 13, pp. 513-519, 2017.

[14] M. Mohamed, Y. Merzoug, and B. Sami - New Strategy to Enhance AC Grid Performance with SVC Device in an Optimal Location, Journal of Ambient Intelligence and Humanized Computing, vol 13, no. 1, 2021.

[15] M. Karami, N. Mariun, Z.A. KadirM - Determining Optimal Location of Static Var Compensator by means of Genetic Algorithm, Electrical, Control and Computer Engineering (INECCE), 2011, International Conference, Vol 10(4).

[16] O. Skoglund - Dynamic voltage regulation using SVC, Asimulation study on the Swedish national grid, Master thesis, KTHUniversity, 2013

[17] International Electrotechnical Commission. Loading Guide for Oil-Immersed Power Transformers; IEC Publications: Geneva, Switzerland, 2006.