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OPTIMIZING THE POWER FLOW STABILITY OF 330KV TRANSMISSION SYSTEM USING STATIC VAR COMPENSATOR

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Abstract: **This work presents optimizing the power flow stability of 330KV transmission system using Static Var Compensator (SVC). The aim is to ensure stability, control and regulation of power flow during times of nonlinearity arising as a result of fault conditions which induces excess reactive and active power within the system. This problem was formulated using Newton Raphson load flow analysis to identify the weak busses. Static Var Compensator (SVC) was developed and used to improve the poor buses identified from the study and then implemented with Simulink. The result showed that the SVC was able to improve the bus performance to achieve voltage profile of 0.95 – 1.05p. The SVC was integrated on the Nigerian 330KV transmission lines and evaluated. The result showed that the characterized bus with poor voltage profile was corrected.**

Keywords: **Power Stability, Transmission Lines, Static Var Compensator, Control, Regulation, fault, load flow studies.**

I. INTRODUCTION

Recently, the demand on transmission system is increasing exponentially with the increase number of loads, utilities and non utility generators. This presented the need for advancement in the power system industry (Onah and Agu, 2017). Power system has grown in complexity as a result of a vast network of transmission interconnections, multiple types of generation resources and loads (Nnaji, 2019). Due to these technological advancements and many other scientific achievements in the last few decades, the quality of life for most people has increased significantly.

Today global population has continued to increase that the present state of the art transmission network are unable to serve effectively in many underdeveloped and developing countries. When population increases, it results to further expansion in terms of industrialization, increased load demand which directly strain the power systems networks, thereby resulting to power quality disturbances, voltage sagging and imbalances in the voltage profile along the electric network.

Power system transient stability study has been an active research area for many decades now. Instability in power system is a state of power flow with active or reactive power above or below the standard specification by the power regulation commission which in the domain of the researcher is the Nigerian Electricity Regulatory Commission (NERC). Other causes of instability include faults among others.

To solve this problem, the simple approach would have been expansion of the power system network like the transmission lines, substation capacity, and number of buses among others; however this is very cost effective and not realizable now due to issues of recession. Traditionally, the use of shunt static capacitors/reactors banks were extensively used to reduce the level of reactive power flowing in transmission and distribution networks. But these elements are costly, bulky and often relatively inefficient.

The use of flexible AC transmission system (FACTS) has been proposed in many studies as an alternative approach to help control this power instability. FACTs devices employed components such as Static Synchronous Compensators (STATCOM), Static Var Compensator (SVC); Unified Power Flow Controller (UPFC) etc. These devices all have their advantages and disadvantages, but the use of SVC has been successfully deployed in many works for power system stability control (Seethavamayya and Ruo, 2013).

The SVC is a shunt compensation equipment of thyristor switched type. It consists of electrical devices for providing fast-acting reactive power compensation on high-voltage transmission networks. SVC consists of devices like Thyristor controlled Reactor (TCR), Thyristor switched capacitor (TSC), Harmonic Filters, Mechanically switched reactors etc (Geza et al., 2018). This research proposes the development of this SVC system for the power flow stability of the Nigerian 330KV transmission system.

The Aim and Objectives of the Study

The aim of the study is to optimize the power flow stability of the 330KV transmission system using Static Var Compensator with the following setout objectives; To perform load flow study of the Nigerian 33KV 30bus transmission network; develop an SVC system and implement on the network using Matlab and to evaluate the performance and validate the results.

II. LITERATRUE REVIEW

AUTHOR	TITLE	TECHNIQUE USED	WORK DONE	RESEARCH GAP
Onah and Agu (2017)	Modeling and analysis of a three phase solid State Var Compensator	Three phase pulse width modulation voltage inverter system	The work examines the performance of a three-phase Solid-State Var Compensator employed in the power system for reactive power compensation. The principal component of this device is a three-phase pulse-width-modulated voltage source inverter	SVC was able to improved voltage stability
Scott et al (2017)	Design of a Microprocessor-Controlled Personal Static Var Compensator (PSVC).	Micro-controller	The work employs microcontroller for the design of Static Var Compensator	The is not reliable for high voltage lines
Ayumu et al., (2017)	New hybrid SVC with series active filter	SVC and active filter	The study used active filter to mitigate harmonic generated from thyristors based SVC controlled power system	The SVC was able to control over current and power factor
Benghanem et al (1999)	Performance Analysis of Advanced Static Var Compensator Using Three-level Inverter	SVC	The study used three level inverter system developed with thyristor to improve the performance of SVC for power system stability.	SVC was able to improved voltage stability
Guk et al (1996)	Analysis and Controller Design of Static Var Compensator Using Three-level GTO Inverter	SVC	In the work a controller was designed using Three-level Inverter and used to improve the efficiency of SVC for optimal power flow control.	SVC was able to improved voltage stability
Geza et al (2018)	Performance Analysis of a PWM Inverter Var Compensator	PWM Inverter Var Compensator	The work evaluates the performance and result of PWM Inverter Var Compensator	SVC was able to improved voltage stability
Patel et al (2018)	Generalized Technique of Harmonic Elimination and Voltage Control in Thyristor Inverters: Part I Harmonic Elimination"	Thyristor Inverters	In the study, harmonics was mitigated using thyristor based inverter system	Harmonics and voltage control was achieved

III. METHODS

The methods used for the development of the new system are empirical data collection and analysis, development of the SVC, implementation of the SVC with simulink and then integration of the SVC on the selected bus with instability.

Empirical Data Collection

The study considered the Nigerian 30 Bus, 33KV transmission network as the testbed and used for data collection via the transmission Company of Nigeria (TCN) and analysis with Newton Raphson load flow algorithm to identify bus with poor voltage profile. The pseudocodia of the load flow analysis was presented as (Ikule et al., 2019; Abdulkarem et al., 2014; Afolabi et al., 2015);

PSEUDO CODE OF NEWTON RAPHSON

```
1. Start
2. Read the phasor parameters values of the busses
3. Read the self admittance for each bus
4. Read mutual admittance between busses
5. Initialize the Y-Bus matrix
6. Compute the driving point admittance using series and shunt admittance
7. Compute the transfer admittance using negative admittance between two uses i and j
8. Check for end bus count
9. Formulate the Y- Bus admittance matrix of the network
10. Assume the initial value of bus magnitude $|V_i|$ and the phase angle $\Theta$ equal to slack quantities.
11. Initialize $|V_i| = 1.00$pu and $\Theta = 0$rad.
12. Initialize count for iteration t =0
13. Compute the real and reactive power for each bus
14. Compute the bus error
15. If
16. Reactive power is within limit = true
17. Then
18. Compute change in real power only.
19. Else if
20. Equate the violated limit as reactive power and treat as PQ Bus.
21. Compute the Jacobian matrix elements using estimated $|V_i|$ and $\Theta$ in step 2
22. Obtain the change of $\Delta|V_i|$ and $\Delta\Theta$ with changes in real and reactive power components of the bus voltage
23. Update $\Delta|V_i|$ and $\Delta\Theta$ at all loads
24. Next iteration with updated $\Delta|V_i|$ and $\Delta\Theta$ values
25. Do
26. Until (scheduled error for all busses are within the specified error tolerance
27. $\Delta P_i^{(r)} < \varepsilon, \Delta Q_i^{(r)} < \varepsilon$ (Where $\varepsilon$ is the tolerance level for the load bus) compute the line flows and power at the slack bus
28. End
```

The result of the load flow analysis was used to determine the load flow parameters of each bus characteristics as shown in the table 1;

Table 1: Line flow characteristic of the Nigeria 30-bus, 330-KV Network (TCN, 2021)

Bus	**Volt profile (p.u)**	**P Flow (p.u)**	**Q Flow (p.u)**	**P Loss(p.u)**	**Q Loss(p.u)**
Alaoji	0.981032	-4.31778	-1.72711	0.021565	0.241136
Sapelle1	1.000000	5.181951	2.695448	0.000614	0.018424
Akangba	0.958026	-36.9771	-23.8358	2.324954	18.54851
Aja	0.998455	50.61477	3.753548	2.241081	19.11358
Jebba	1.000000	-18.8374	-8.02673	0.736981	6.306458
Kaduna	0.747704	1.863246	3.194321	0.007259	0.061635
New Haven	0.845679	-18.951	-18.9252	0.636623	4.430379
Shiroro	1.000000	8.814445	4.154353	0.006172	0.052461
Ugwuaji	0.743033	-8.63556	-4.17725	0.131603	1.126146
Afam	1.000000	-3.59135	-4.35942	0.031638	0.271237
Ajaokuta	0.991724	-11.7177	-12.5704	0.323727	2.252874
Aladja1	0.997646	8.85365	4.473013	0.077555	0.067776
Ayede	0.946013	-5.18134	-1.72711	0.009071	0.077289
Benin1	0.986123	8.85365	4.473013	0.077555	0.067776
Delta1	1.000000	-1.5E-13	8.23E-14	2.52E-29	1.26E-29
Egbin	1.000000	-11.2478	-6.07014	0.670029	5.712877
Geregu1	1.000000	-19.0858	-1.94633	0.344185	0.267699
Gombe	0.481268	-25.0724	-18.2424	0.229136	1.791423
Gwagwa	0.977903	6.132487	4.925603	0.04753	-4.49868
Ikeja W	0.960772	24.99649	30.9299	0.529768	5.156408
Jos	0.631068	10.79445	17.39072	0.125687	1.223355
Kainji	1.000000	-3.87477	-9.15351	0.071948	0.610319
Kano	0.699970	5.848547	0.426743	0.031468	0.024475
Kantanpe	0.977903	-2.20338	-3.89174	0.013829	-5.39709
Kebbi	0.993249	8.635562	2.051427	0.023634	0.230041
Makurdi	0.668612	3.175867	-0.34198	0.004678	-1.15361
Okpai	1.000000	-6.08653	-6.47034	0.017853	0.154181
Onitsha	0.946346	13.33166	8.199671	0.123436	1.047949
Oshobo	0.947324	51.08352	-1.33086	0.574485	6.423791
Yola	0.469706	-14.0472	-7.90669	0.048096	0.371410

The data in table 1 presented the load flow parameters of the conventional Nigerian 330KV 30Bus transmission network. From the analysis the bus voltages outside the statutory limit of 0.95 – 1.05p.u for voltage profile such as bus (Jos) with value 0.8171pu, bus (Gombe) 0.8144p.u bus (Kaduna) 0.747704pu, bus (Maiduguri) 0.668612pu, bus (Ugwuaji) 0.743033, bus Newhaven 0.84567 bus (Kano) 0.747704pu, and bus Yola 0.476706 are identified and presented in the table 2 for corrections.

Table 2: Buses with low voltage profile

Bus	**Volt profile**	**P Flow**	**Q Flow**	**P Loss**	**Q Loss**
Gombe	0.481268	25.07240	18.24240	0.229136	1.791423
Jos	0.631060	10.79445	17.39072	0.125687	1.223355
Makurdi	0.668612	3.175867	0.341980	0.00467	-1.15361
Kano	0.699970	5.848547	0.426743	0.031468	0.024475
Ugwuaji	0.743033	8.635560	4.177250	0.131603	1.126146
Makurdi	0.668612	3.175867	0.341980	0.00467	-1.15361
Kaduna	0.747704	1.863246	3.194321	0.007259	0.061630
New Haven	0.845670	18.9510	18.92520	0.636623	4.430379
Yola	0.469706	14.0472	7.906600	0.048096	0.371410

IV. DEVELOPMENT OF THE STATIC VAR COMPENSATOR

The Static VAR Compensator (SVC) is one of the shunt connected FACTS devices, which is based on power electronics. It helps in voltage regulation, reactive power control and improving the transient stability of the system. The voltage regulation by SVC is done, by controlling the amount of reactive power injected into or absorbed from the power system. It generates reactive power (capacitive mode), when the system voltage is low and absorbs reactive power (inductive mode), when the system voltage is high (Yehia et al., 2019).

A typical SVC comprises of one or more banks of switched shunt capacitors or reactors, of which at least one bank is switched by thyristors. The reactive power variation can be achieved by switching the capacitor banks and inductor banks. The capacitors are switched ON and OFF by Thyristor Switched Capacitor (TSC) and the reactors are controlled by Thyristor Controlled Reactor (TCR). The current in the reactor can be varied using Firing delay angle control method, which is shown in Figure 1;

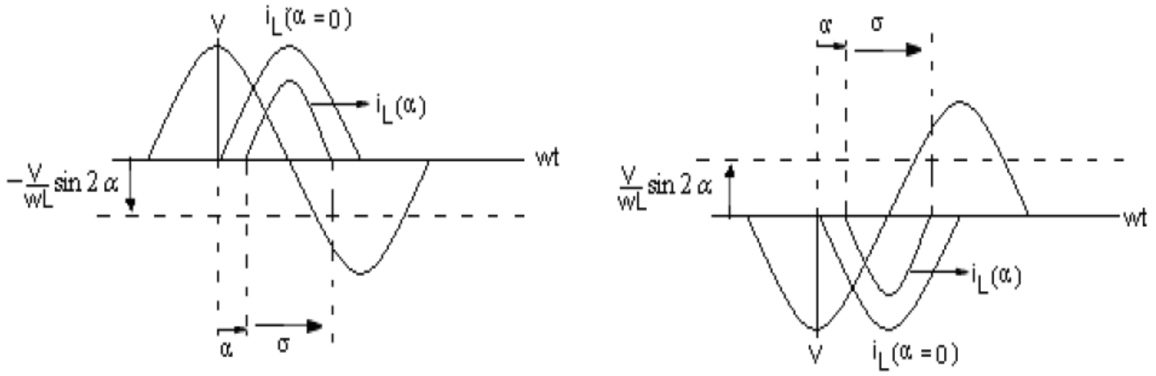

Figure 1: firing delay angle control

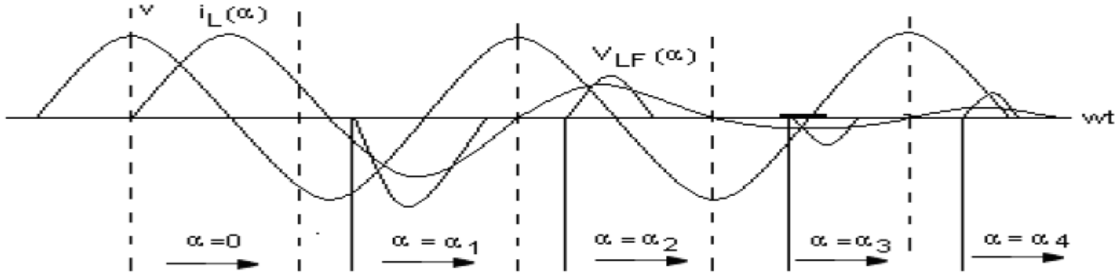

Figure 2: SVC Operation waveform

From the Figure 2, it is evident that the reactive current magnitude can be varied from maximum (α=0) to zero (α=π/2). The term iL(α) represents reactor current and iLF(α) is its fundamental component. The dynamic equation of SVC is given as,

$$\frac{d\Delta BL}{dt} = \frac{1}{T\alpha}\left[-\Delta BL + K\alpha\,(Vref - Vt + \Delta Vs)\right] \qquad (1)$$

Where Tα and Kα are time and gain constants respectively; the susceptance BL, is associated with the reactive power injected into the system in order to maintain the voltage level between suitable limits. The variable inductive susceptance BL is given by

$$BL = \frac{-(2x-2\alpha+\sin 2\alpha)}{\pi xs,},\ \pi/2 \le \alpha \le \pi \qquad (2)$$

Where xS is the reactance of the fixed inductor of the SVC and α is the thyristor firing angle. Figure 3 shows the basic architecture of SVC Control scheme. This model is known as Phasor type in MATLAB, which can be used for transient stability studies and to observe the impact of SVC on electromechanical oscillations and transmission capacity.

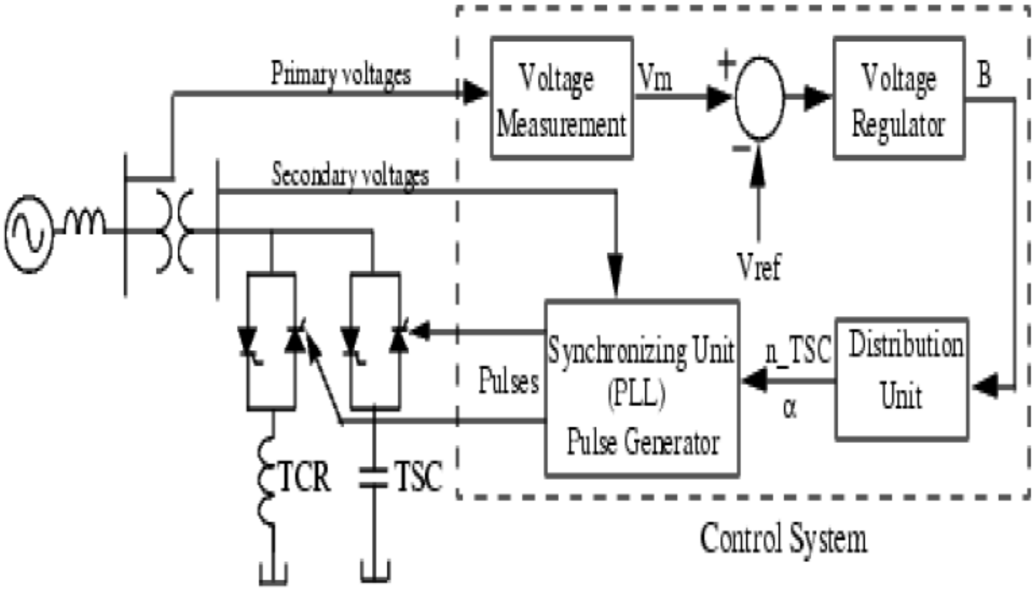

Figure 3: The SVC block diagram

The block consists of a Step down transformer, Voltage regulator, TCR and TSC units, a Phase Locked Loop (PLL). The functions of the above blocks are:

- Positive sequence voltage is measured using a Voltage Measurement system.
- The Voltage regulator uses the voltage error to calculate the susceptance (B) of SVC in order to maintain a constant system voltage.
- The distribution unit computes the firing angle (α) for TCRs.
- The synchronizing unit uses a PLL to synchronize secondary voltage and the pulse generator sends the required pulses to the thyristors.

The single line diagram of the improved SVC model, in line with the power system to be controlled is presented in figure 4;

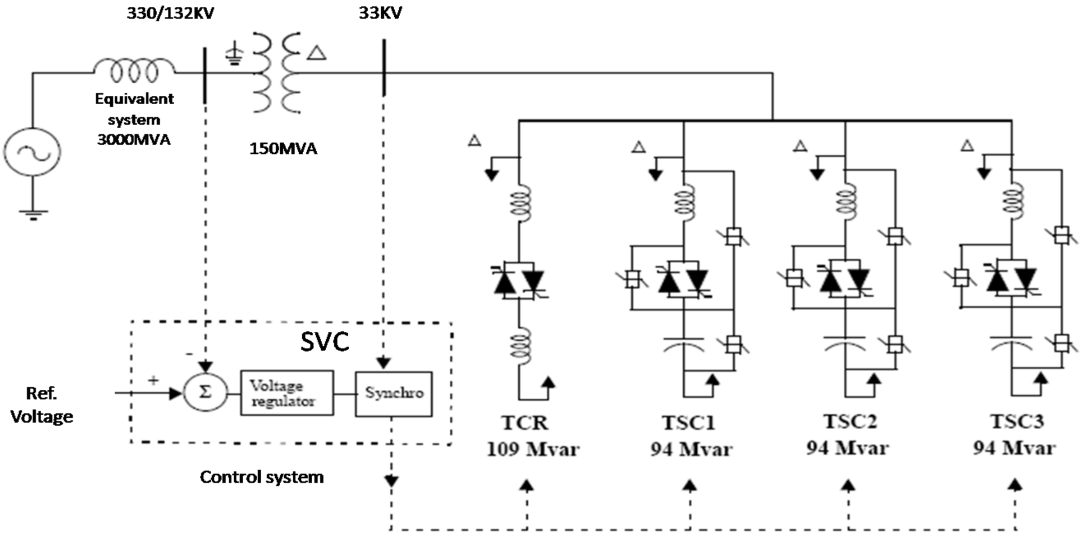

Figure 4: the thyristor SVC with transmission system block

The figure 4 shows how the SVC was installed on the transmission line to control instability on the line and ensure quality of load flow.

V. IMPLEMENTATION

This section presented the implementation of the SVC developed on a selected bus for performance evaluation purposes. This was done using power system toolbox, optimization toolbox and simulink as shown in the figure 5;

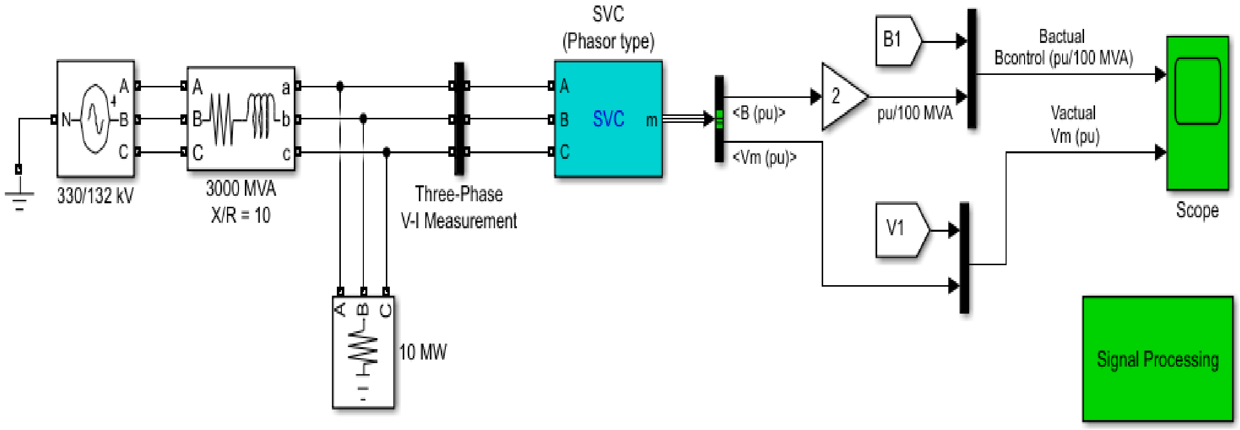

Figure 5: The implemented SVC on a selected bus.

From the figure 5 the SVC was implemented on a selected bus (B1) identified from the empirical study as having issues of poor voltage stability profile. The model was simulated using the parameters in the table 3 which was collected from the network during the empirical data collection.

Table 3: Simulation parameters

Module	**Parameter**	**Definition**	**Typical value**
Thyristor switch	T_d	Gating delay	0.001s
Thyristor control	T_b	Firing Delay	0.003-0.006s
Voltage regulator	K_i	Integrator gain	Ki can be varied
Slope	X_{SL}	Steady gain error	0.001 – 0.05 p.u
Measurement	T_m	Time constant	0.01- 0.005s

VI. RESULTS AND DISCUSSIONS

The performance of the SVC at the Bus to control this reactive or active power flow was presented and analyzed using the IV characteristics curve in figure 6;

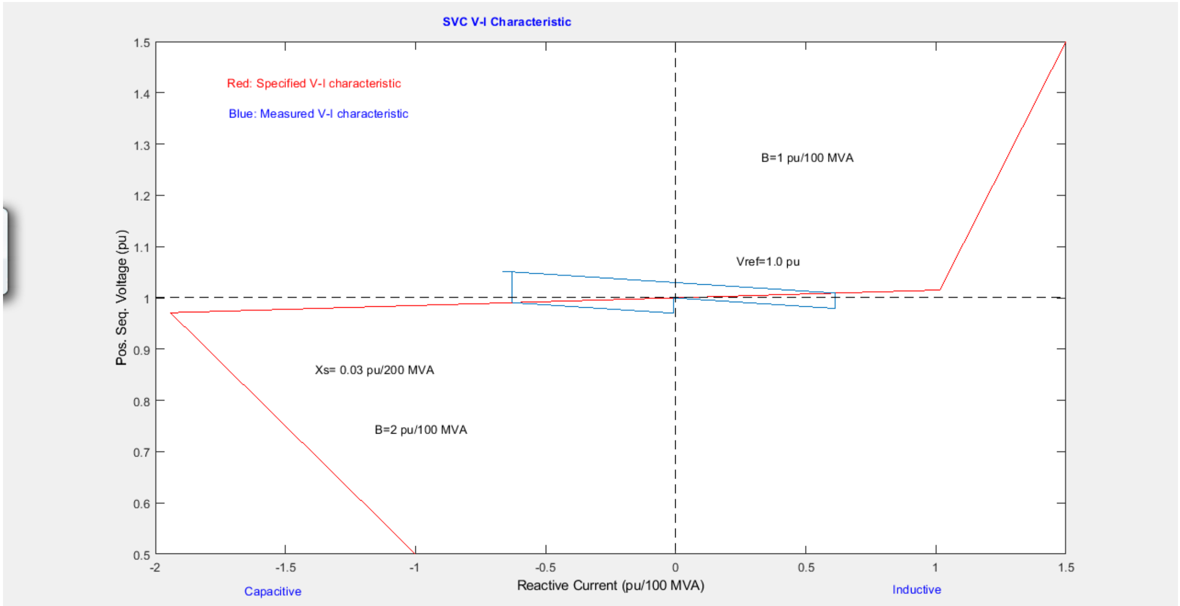

Figure 6: The phasor characteristics of the SVC

The figure 6 presented the behavior of the SVC during instability. It was observed that the SVC operates as a controller when the reactive power is excess by keeping the susceptance within the maximum and minimum values imposed by the total reactive power of capacitor bank (BCmax) and the reactor band (BI max), the voltage regulator is regulated at the reference voltage ref. From the result when the reactive power flow in the bus increases at 0.1s the SVC acts as inductance and absorbs 200MVA of reactive power. This variation of reactive power is performed by switching three-phase inductor banks connected on the secondary side of a coupling transformer to restore stability and control the system. Again when the reactive power flow was reduced at 0.4s, the SVC injected reactive power of 100MVA to the system to regulate the power in the bus. The variation of reactive power is performed by switching three-phase capacitor banks connected on the secondary side of a coupling transformer. The transient stability response at the bus voltage profile was studied using the figure 7;

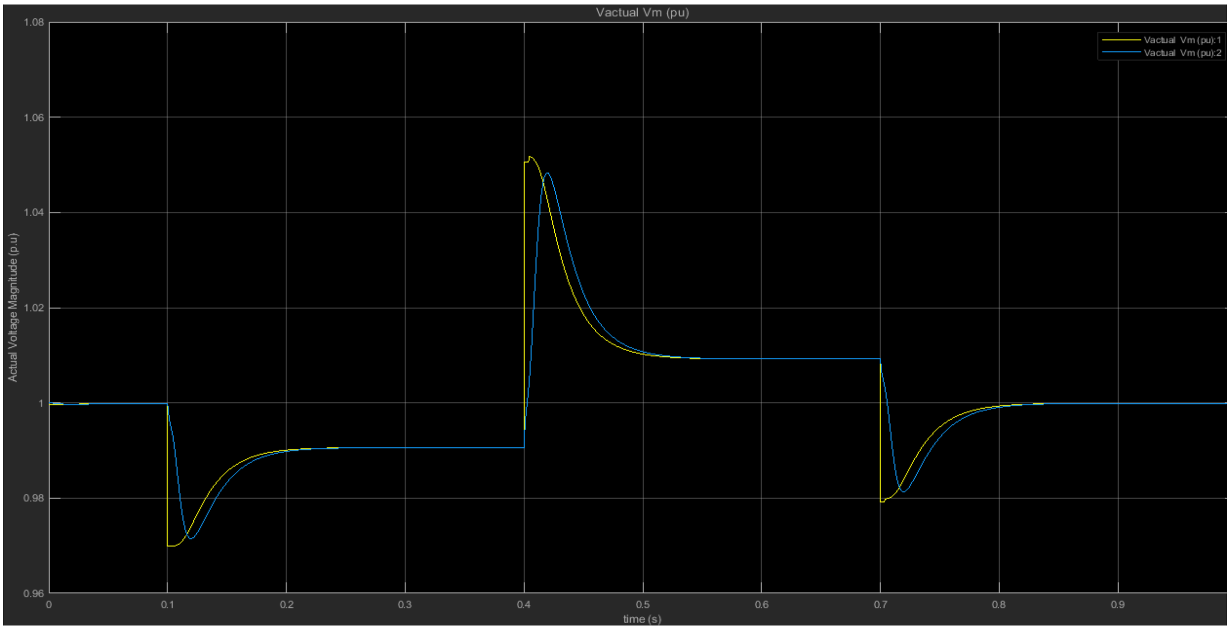

Figure 7: Regulation and control response of the SVC on the Bus

The result in the figure 7 shows the behavior of the Bus with the SVC installed to control unstable reactive power flow in the system. In the result it was observed that at 0.1s when the voltage profile drops to 0.97 (p.u) due to increased reactive power flow, the SVC absorbs the reactive power using the capacitor band to restore the voltage profile to 0.99 (p.u) as shown at 0.2s, also at 0.4s when the instability was again experienced in the system resulting to excess voltage profile of 1.05, exceeding the tolerable profile specified of the system, the SVC regulated the power flow by injecting reactive power to restore the voltage profile to 1.00 (p.u) as shown at 0.8s.

System Integration with the SVC

This section presented the system integration of the SVC after the result in the figure 7 has shown its capability in controlling active and reactive power flow to achieve stability. The result when deployed on other selected buses characterized with poor voltage profile is presented in table 4;

Table 4: Corrected Bus with SVC

Bus	**Volt profile**	**P Flow (MVA)**	**Q Flow (MVA)**
Gombe	1.001268	25.0724	18.2424
Jos	1.001416	10.79445	17.39072
Makurdi	1.010112	3.175867	0.34198
Kano	1.010197	5.848547	0.426743
Ugwuaji	1.000000	8.635560	4.17725
Makurdi	1.010612	3.175867	0.34198
Kaduna	1.011704	1.863246	3.194321
New Haven	1.000000	18.95100	18.9252
Yola	1.010116	14.04720	7.9066

The table 4 presented the bus analysis of the case study selected buses with instability, integrated with SVC and then monitored as reported in the above table. The result showed that the Busses were corrected as the active and reactive power flow was controlled by the SVC and achieved a voltage profile which satisfied the standard bus statutory limit of 0.95 – 1.05p.u.

Comparative analysis

This section presented the comparative bus analysis of the selected buses without SVC and the improved busses with SVC as shown in table 5;

Table 5: Comparative bus profile

Bus Names	Volt profile with SVC (p.u)	Volt profile without SVC (p.u)
Gombe	1.001268	0.481268
Jos	1.001416	0.63106
Makurdi	1.010112	0.668612
Kano	1.010197	0.69997
Ugwuaji	1.000000	0.743033
Makurdi	1.010612	0.668612
Kaduna	1.011704	0.747704
New Haven	1.000000	0.84567
Yola	1.010116	0.469706

The data presented in the table 5 shows the result of the Buses with SVC and without SVC performance. This result was analyzed using the graph in figure 8;

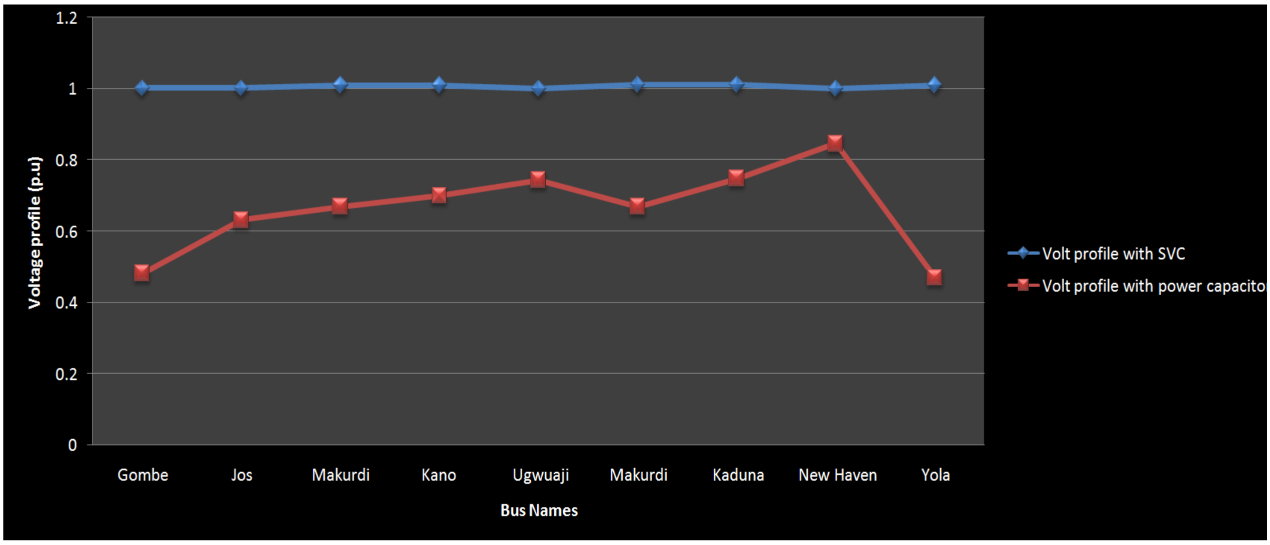

Figure 8: Comparative Bus Voltage profile

From the result in figure 8, it was observed that the SVC was able to control and regulate power flow at the unstable busses identified from the empirical study. The implication of the result showed that the SVC was able to achieve transient stability and improve the quality of power flow.

VII. CONCLUSION

The Nigerian 330KV grid system is characterized with various challenges due to over load, aging materials and equipments used to operate the system, which results to instabilities, poor quality of power supply, losses, deregulation of voltage among others, and have generally affected the reliability of the system nationwide. This study have addressed the problem formulated with load flow analysis using an automated approach which controls and regulated active and reactive power flow using Static Var Compensator. The result showed that the Buses with instability were corrected and quality of power was restored in the Nigerian 330KV, 30Bus Transmission Networks.

CONTRIBUTION TO KNOWLEDGE

The study improved the performance of the Nigerian 330KV transmission Network using Static Var Compensator

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