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Performance Evaluation of Optimally Placed SVC for Dynamic Stability of the Power System

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ABSTRACT: Given the complexity of power systems, particularly in the deregulated power industry found in Nigeria, a consistent, safe, controllable, and high-quality power supply is required. The loss of the system's overall damping torque, which reduces the system's susceptibility to fluctuations and problems with dynamic stability, is one of the key downsides of network expansion. Flexible AC transmission systems (FACTS) controllers have been used to overcome problems with power system stability control. In order to improve dynamic stability, this study investigates how the generator's rotor angle, speed, voltage magnitude profile, and real power affect how well SVC operates under the effect of a three-phase fault. With a fault introduced on Bus 33 (Geregu Substation) and SVC placed optimally on Bus 21 (Jos Transmission Station) using voltage stability sensitivity factor (VSSF) after the simulation of continuation power flow (CPF), the 48-bus power system network in Nigeria was modeled using commercial PSAT software in a MATLAB environment. The power system's oscillation was significantly reduced, and the voltage profile was enhanced for power system dynamic stability, per simulation results with and without SVC.

KEYWORDS: optimally placed, SVC, FACTS, dynamic stability, VSSF.

I. INTRODUCTION

The transmission and distribution systems are the two crucial nodes connecting generation and consumption in the operation of the power systems as a whole. Making the best use of the current transmission lines becomes a strict necessity for the power systems because there is no right of way for the transmission of electrical energy (Omorogiuwa & Okpo, 2015; Innocent, Nkan, Okpo, & Okoro, 2021; Awah, Okoro, Nkan, & Okpo, 2022). Because of the limited right-of-ways and the expanding nature of the power system caused by the rising energy demand, moving electricity from generation to load centers presents a significant challenge. As a result, it is crucial to make the best use of the few available transmission facilities in order to maximize energy transfer. Power transmission via lengthy transmission lines that encounter voltage changes also presents issues. By regulating and enhancing the structures' ability to transport power, it will be possible to manage the security issues that could also manifest in this situation as transient and steady state instability and better meet the rising energy demand (Nkan, Okpo, & Inyang, 2023; Sayyed, Gadge, & Sheikh, 2014). Additionally, as a result of problems with voltage, angle, and frequency stability, operational problems also get more challenging (Okpo & Nkan, 2016; Abunike, Umoh, Nkan, & Okoro, 2021). Power system stability refers to an electric power system's ability, given a specified initial operating condition, to revert to a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bound so that practically the entire system remains intact (Nkan & Okpo, 2016). This study's goal is to investigate how Nigeria's 330 kV, 48-bus power system network might use FACTS devices like SVC to enhance dynamic stability.

II. LITERATURE REVIEW

The growing energy demand due to advancement in technology in recent time demands bulk electric power supply from the main grid, leading to energy utilization peak and significant distortion of the grid voltage and frequency. Dynamic loads have a significant impact on the grid frequency and power stability, necessitating the adoption of advance control strategies to ensure optimal power flow in the complex power system network (Innocent, Nkan, Okpo, & Okoro, 2021; Ezeonye, Nkan, Okpo, & Okoro, 2022). The power supply from the main grid is erratic, therefore, novel means to enhance efficient power utilization is imperative in order to meet the increasing electric power demands. The studies carried out by (Ahmad & Sirjani, 2020; Srivastava, Singh, & Upadhyay, 2002; Nkan, Okpo, & Okpura, 2023),showed that optimal allocation of FACTS devices using the meta-heuristic techniques will improve the performance of power systems. The studies carried out a comparative analysis between other advanced approaches (analytical methods and linear programming) and meta-heuristic strategies methods critically, from which the meta-heuristic approaches gave the best solutions for solving complex multi-objective, and discrete problems. To avoid instability and voltage limit violation during severe contingencies and over voltage conditions, Immediate operator actions are crucial. Studies by (Dixit, Srivastava, Singh, & Agnihotri, 2015; Gupta, Rathor, & Jain, 2018; Khusalani, Dhaked, & Sharma, 2018; Mirabadi, Abjadi, Hoghoughi-Isfahani, & Shojaeian, 2014), developed novel approaches for the system recovery during contingencies. Power system restructuring and utilization of FACTS devices were deployed; specifically Thyristor controlled series compensators (TCSC) and Thyristor controlled phase angle regulators (TCPAR), to optimize line parameters and enhance stability. The proposed method was tested on IEEE 14-bus system using power world simulator version 12.0 and the outcome showed a significant cost saving in power production and improved the security of supply. Moreover, maintaining secure operation conditions in power system network presents significant challenges to power engineers. The integration of FACTS controllers addresses the power instability issues particularly, Static Var compensators (SVCs) which are often employed to enhance voltage profile and stability in power systems when optimally placed as was carried out by (Udgir, Varshney, & Srivastava, 2011; Nkan, Okpo, & Okoro, 2021) with consideration given to a single line outage contingencies on IEEE 30-bus and the Nigerian 48-bus systems respectively. Optimization and placement of shunt FACTS devices along transmission lines to enhance control and power transfer capacity was performed by (Natala, Udofia, & Ezenkwu, 2017). The authors deployed mathematical models for available power transfer on both lossless and real transmission lines and validation was done using MATLAB simulation software. The study also evaluated the performance of the power system, highlighting that the optimal location of FACTS devices offered potential enhancements in power transfer capability and system stability when it was optimally placed. In order to optimize the placement of FACTS controllers, Real Coded Genetic Algorithm (RGA) was deployed by (Medeswaran & Kamaraj, 2014; Joshi & Sahay, 2017; Nwohu, 2010) for the placement of Thyristor Controlled Series Capacitor (TCSC) and Unified Power Flow Controller (UPFC) FACTS devices in power systems, considering line thermal limits and voltage constraints. Demonstration of improved loadability and validating RGA's effectiveness on IEEE 6 and 30 bus systems was effectively carried out by the authors. The studies carried out by (Natala, Nkan, Okoro, & Obi, 2023; Ndubuka & Sadiq, 2015; Retnamony & Raglend, 2016),focused on improving the transfer capability of the Nigerian 58-bus, 330kV power system network through the strategic placement of FACTS devices. The outcome showed that Unified Power Flow Controllers (UPFC) performed better than Thyristor Controlled Series Compensator (TCSC) and Interline Power Flow Controller (IPFC) in enhancing power transfer capability. Theoretical foundations of power line transmission was explored by (Penjiyev, 2008; Nkan, Okpo, Akuru, & Okoro, 2020). The study differentiated between conventional thyristor-based and fully controlled semi-conductor-based FACTS devices. MATLAB simulation of STATCOM, SVC, and SSSC was done to provide a comprehensive analysis on the performances of these FACTS devices. Impact of STATCOM controllers on distance protection relays was investigated by (Subramanian, 2010).He envisaged that at 220 kV, similar solidly grounded systems, distance relays may malfunction and increase operating times when STATCOM is in service, emphasizing the need for corrective actions and further research in this area. In response to the escalating power demand and challenges encountered in heavily loaded transmission lines (Narain & Srivastava, 2015; Tripathi & Pandiya, 2017), explored utility FACTS devices specifically SSSC, TCR, TCSC, STATCOM, and UPFC. They stated that these controllers can be used to address power instability, voltage sags and other numerous transmission line issues. Also utilization of FACTS devices was further explored by (Bindal, 2014; Singh, Verma, Mishra, Maheshwari, Srivastava, & Baranwal, 2012). This controllers were used to optimize existing high voltage AC transmission infrastructure in response to economic and environmental constraints in developing countries thereby, enhancing transmission line efficiency and environmental benefits. The study carried out by (Nkan, Okoro, Awah, & Akuru, 2019) Investigated the application of a Static Synchronous Series Compensator (SSSC) in the Nigerian 48-bus power system to enhance transient stability by analyzing system responses during a three-phase fault, demonstrating improved damping of power system oscillations and enhancement of voltage profile for dynamic stability using MATLAB and PSAT software. The significant impacts FACTS devices including UPFC, TCSC, and STATCOM have on voltage improvement were studied by (Eseosa & Odiase, 2012).The outcome showed significant line loss reduction in a 330 kV transmission network in Nigerian. The authors deployed a genetic algorithm (GA) optimization approach, with UPFC yielding the most significant loss reduction of 48.64% in the system. A comprehensive overview of the development, practical installations, benefits, applications, and challenges associated with FACTS controllers was carried out by (Acharya, Sode-Yome, & Mithulananthan, 2005). The study covers the historical development, global installations, benefits, costs, applications in deregulated markets, and challenges while offering real world case studies for analysis. The study by (Nkan, Okoro, Awah, & Akuru, 2019) , Investigated the enhancement of steady state stability in the Nigerian 48-bus power system network, addressing voltage instability issues resulting from industrial expansion and deregulation through the strategic placement of SSSC FACTS controllers. In their bid to enhance transient stability in electric power system, (Nkan, Okoro, Obi, Awah, & Akuru, 2019)also demonstrated the application of Static VAR Compensator (SVC) and Static Synchronous Compensator (STATCOM) within the Nigerian 48-bus power system network. The study emphasized that optimal placement of these FACTS devices at Bus 21(Jos Transmission Station) through power flow simulations and eigenvalue stability analysis showed that SVC have a better performance than STATCOM in terms of negative eigenvalues for improved power system stability and damping of oscillations.

III. METHODOLOGY

A. Modeling of The Nigerian 48-Bus System with SVC and Three Phase Fault

Figure 1 shows a model of the Nigerian 48-bus system, which includes 20 load buses, 51 transmission lines, 14 generators, 14 transformers, and 14 generators, for dynamic stability with the best site of SVC following application of a three phase fault at bus 33 (Geregu subatation). Utilizing MATLAB's PSAT software, this was accomplished. The Nigerian power system network's bus data and transmission line input data were retrieved from (Umoh, 2022).

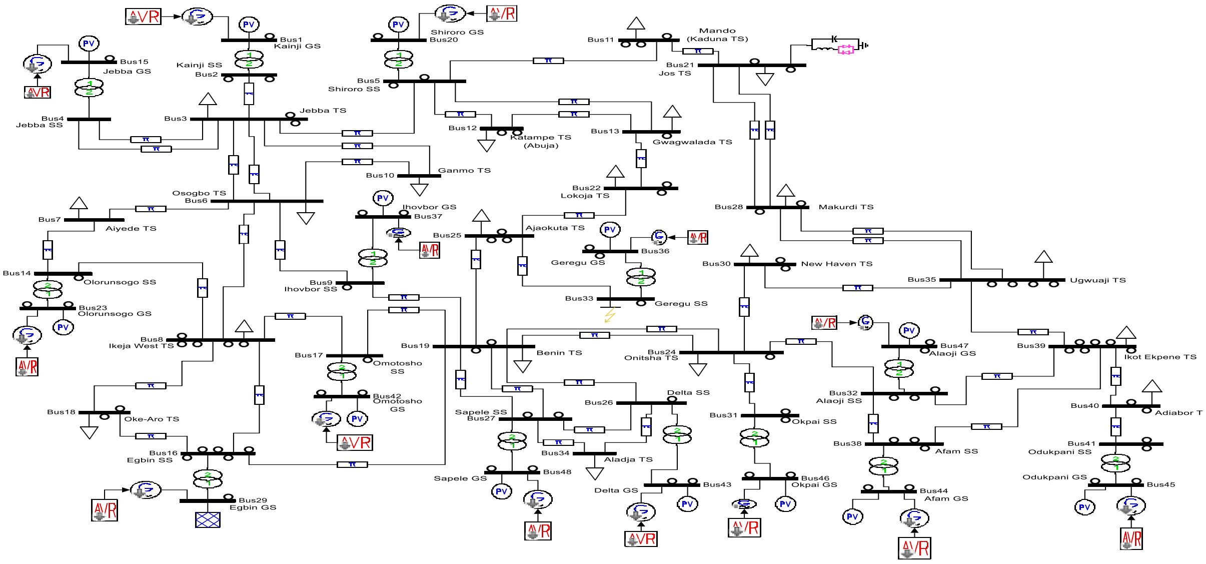

Figure 1. Nigerian 48-bus system; fault at bus 33, SVC on bus 21

B. Power Flow Multi-Control Function with SVC

Figure 2 shows the SVC model that was employed in this investigation while taking the firing angle into account and assuming a balanced fundamental frequency operation. The equations in algebra and differential calculus are:

$$\dot{V}M = (K_m V - vm)/T_m \tag{1}$$

$$\dot{\alpha} = (-K_{D\alpha} + K\frac{T_1}{T_2 T_m}(vm - K_m V) + K(V_{ref} + vPOD - vm))/T_2 \tag{2}$$

$$Q = \frac{2\alpha - \sin 2\alpha - \pi(2 - \frac{XL}{XC})}{\pi XL} V^2 = b_{svc}(\alpha) V^2 \tag{3}$$

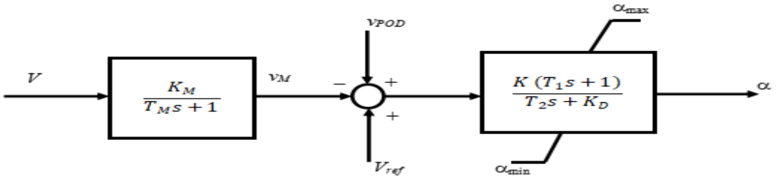

Figure 2. SVC Type 2 regulator

The SVCs state variables are initialized after the power flow solution. To ensure that the necessary voltages are applied to the compensated buses, a PV generator with no active energy should be utilized. After applying the SVC equations and the energy flow solution, the PV bus will be deleted.

IV. RESULTS

A. Nigerian 48-Bus Without Fault

Newton Raphson power flow simulation was carried out on this system and in 0.187s, the stimulation converges at 1.9382×10^{-9}p.u. after 5 iterations. Time domain simulation (TDS) in PSAT embedded in MATLAB using the Trapezoidal integration method

(TIM) was carried out for Transient stability analysis (TSA). Dynamic simulation (DS) was also completed in 5.8765s with maximum real and reactive power mismatch of 4.84504 p.u. and 1.95 p.u. respectively. The result of the power flow is shown in Table 1

Table I. Power flow results of Nigerian 48-bus system for transient stability analysis

BUS NO	BUS NAME	VOLTAGE (pu)	PHASE ANGLE (rad)	REAL POWER (pu)	REACTIVE POWER (pu)
1	Kainji GS	1.0	-0.08753	2.59	0.10581
2	Kainji SS	1.0065	-0.24906	0	0
3	Jebba TS	1.004	-0.31097	-2.6	-1.19
4	Jebba SS	1.004	-0.30789	0	0
5	Shiroro SS	0.99055	-0.41357	0	0
6	Oshogbo TS	1.0117	-0.32033	-1.07	-0.56
7	Ayede TS	0.99741	-0.32876	-1.14	-0.68
8	Ikeja West TS	0.98066	-0.32636	-4.47	-1.95
9	Ihovbor SS	1.0299	-0.23366	0	0
10	Ganmo TS	1.0029	-0.32646	-1	-0.57
11	Kaduna TS	0.98933	-0.46977	-1.02	-0.51
12	Katampe TS	0.96212	-0.46539	-2.01	-1.07
13	Gwagwalada TS	0.96587	-0.45766	-1.2	-0.65
14	Olorunsogo SS	0.99758	-0.30346	0	0
15	Jebba GS	1.0	-0.16028	2.52	0.11734
16	Egbin SS	0.98686	-0.29182	0	0
17	Omotosho SS	1.0285	-0.24153	0	0
18	Okearo TS	0.97903	-0.32385	-2.2	-1
19	Benin TS	1.0153	-0.30267	-2.57	-1.08
20	Shiroro GS	1.0	-0.22184	3.02	0.44165
21	Jos TS	0.99668	-0.52377	-2.32	-1.1
22	Lokoja TS	0.96676	-0.42346	-1	-0.6
23	Olorunsogo GS	1.0	-0.20368	1.59	0.11803
24	Onitsha TS	1.0035	-0.30458	-1.8	-0.85
25	Ajaokuta TS	0.97206	-0.40232	-1.2	-0.7
26	Delta SS	1.0139	-0.27952	0	0
27	Sapele SS	1.015	-0.2883	0	0
28	Makurdi TS	1.0039	-0.46706	-1.6	-0.72
29	Egbin GS	1.0	0.0	4.845	0.93581
30	New Heaven TS	0.99847	-0.37499	-1.36	-0.77
31	Okpai SS	1.0053	-0.2647	0	0
32	Alaoji SS	0.99864	-0.2142	0	0
33	Geregu SS	0.98562	-0.3353	0	0
34	Aladji TS	1.0097	-0.29134	-1.82	-0.77
35	Ugwuaji TS	0.98946	-0.37849	-1.25	-0.69
36	Geregu GS	1.0	-0.25913	1.2	0.27584
37	Ihovbor GS	1.0	-0.08749	2.4	-0.30275
38	Afam SS	0.99825	-0.20542	0	0
39	Ikot Ekpene TS	0.99105	-0.23741	-1.65	-0.74
40	Adiabor TS	0.98728	-0.20438	-0.9	-0.48
41	Odukpani SS	0.98869	-0.19134	0	0
42	Omotosho GS	1.0	-0.12704	1.88	-0.34825
43	Delta GS	1.012	-0.10752	2.81	0.21084
44	Afam GS	1.003	-0.02974	2.8	0.32277
45	Odukpani GS	1.0	-0.02624	2.6	0.39616
46	Okpai GS	1.0	-0.12687	2.21	0.06808
47	Alaoji GS	1.0	-0.06343	2.4	0.20311
48	Sapele GS	1.0	-0.18743	1.7	-0.15135

Figures 3-6 shows the responses of the rotor angle, rotor speed, voltage magnitude profile and real power of the buses respectively for all the 14 generators of the Nigerian 48-bus power system network of Figure 1 when there was no perturbation.

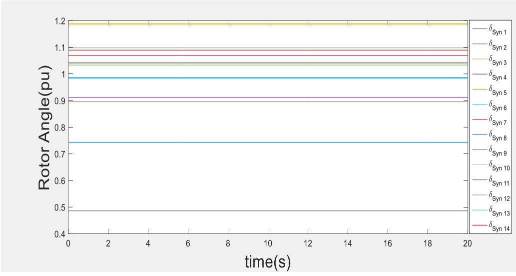

Figure 3. Generators rotor angle responses without fault

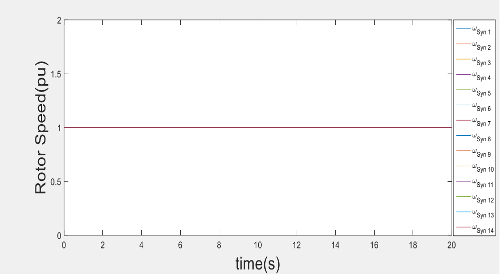

Figure 4. Generators rotor speed responses without fault

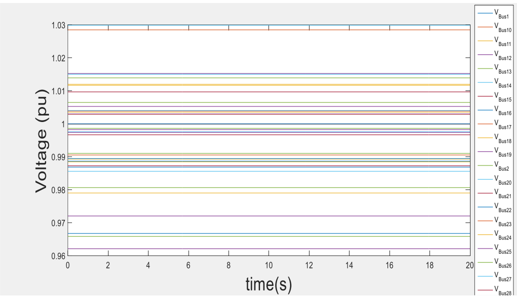

Figure 5. Voltage magnitude profile without fault

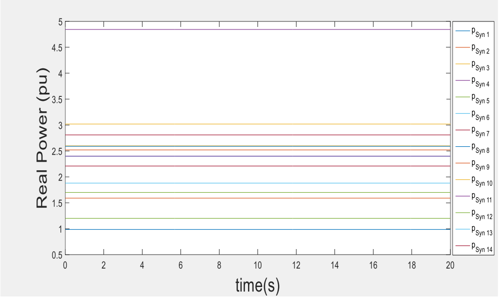

Figure 6. Generators real power responses without fault

B Nigerian 48-Bus System with Application of Fault

A three-phase fault with start and clearing time of 1.00s and 0.153s respectively was applied at bus 33(Geregu SS). It should be noted that the choice of the position for the application of fault was arbitrarily made since fault can occur anywhere in the system. Newton Raphson power flow simulation was performed on the system and convergence was reached after 5 iterations in 0.25s. Time domain simulations was also carried out to enhance dynamic response of the system to the fault. The dynamic simulation was completed in 12.5717s on a scale of 20s. Responses of the rotor angle, speed, voltage magnitude and real power are depicted in Figures 7-10.

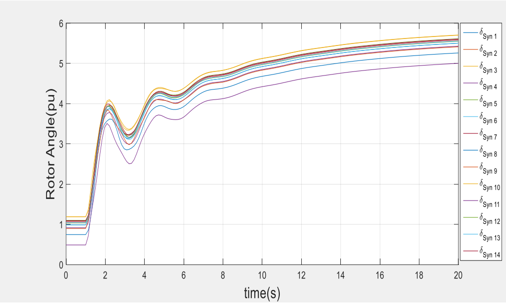

Figure 7. Generators rotor angles with fault

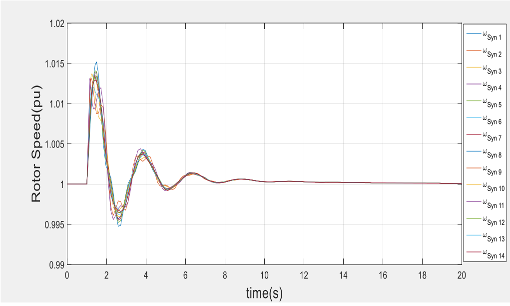

Figure 8. Generators rotor speed with fault

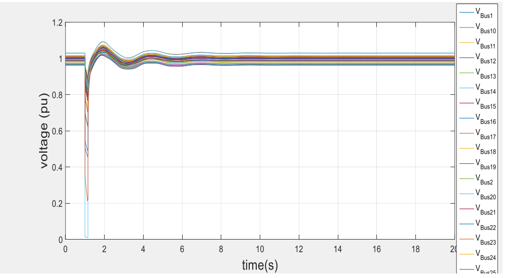

Figure 9. Voltage magnitude profile with fault

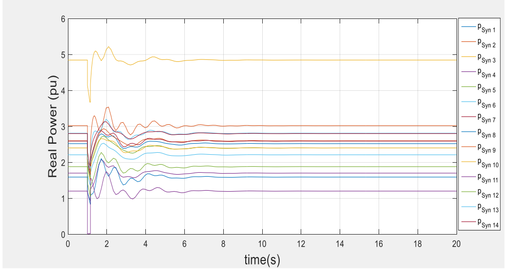

Figure 10. Generators real power responses with fault

C. Optimum Location of SVC using Voltage Stability Sensitivity Factor

The voltage stability sensitivity factors given by the ratio $|\Delta V_i/\Delta V_{total}|$ was computed for all the load buses as shown in Table 3 after the simulation for continuation power flow was completed (Table II). It can be observed that Jos transmission line on bus 21 has the highest sensitivity factor of 0.45519 hence, it is the weakest and most insecure bus, therefore, the reference bus for the placement of SVC devices.

Table II Continuation power flow (CPF) results of Nigerian 4bus system for transient stability analysis

BUS NO	BUS NAME	VOLTAGE (p.u.)	PHASE ANGLE (rad)	REAL POWER (p.u.)	REACTIVE POWER (p.u.)
1	Kainji GS	1.0	-0.3068	4.2972	1.2306
2	Kainji SS	0.95822	-0.40975	0	0
3	Jebba TS	0.92027	-0.52063	-4.3138	-1.9744
4	Jebba SS	0.924	-0.51516	0	0
5	Shiroro SS	0.8188	-0.844	0	0
6	Oshogbo TS	0.91388	-0.51198	-1.7753	-0.92913
7	Ayede TS	0.90281	-0.49124	-1.8915	-1.1282
8	Ikeja West TS	0.86832	-0.41292	-7.4165	-3.2354
9	Ihovbor SS	0.9542	-0.4016	0	0
10	Ganmo TS	0.90563	-0.53914	-1.6592	-0.94573
11	**Kaduna TS**	**0.69135**	**-1.0134**	**-1.6924**	**-0.84618**
12	**Katampe TS**	**0.73763**	**-0.9794**	**-3.3349**	**-1.7753**
13	**Gwagwalada TS**	**0.74688**	**-0.95828**	**-1.991**	**-1.0785**
14	Olorunsogo SS	0.92935	-0.4117	0	0
15	Jebba GS	1.0	-0.41633	4.1811	2.6517
16	Egbin SS	0.89274	-0.29937	0	0
17	Omotosho SS	0.81462	-0.76092	-7.4165	-3.2354
18	Okearo TS	0.87299	-0.38693	0	0
19	Benin TS	0.91584	-0.5949	-4.2641	-1.7919
20	Shiroro GS	1.0	-0.72498	5.0107	6.9887
21	**Jos TS**	**0.54149**	**-1.2887**	**-3.8493**	**-1.8251**
22	**Lokoja TS**	**0.76864**	**-0.87242**	**-1.6592**	**-0.9955**
23	Olorunsogo GS	1.0	-0.33709	2.6381	2.0155
24	Onitsha TS	0.89512	-0.60818	-2.9865	-1.4103
25	**Ajaokuta TS**	**0.79118**	**-0.82062**	**-1.991**	**-1.1614**
26	Delta SS	0.97175	-0.55948	0	0
27	Sapele SS	0.94283	-0.57117	0	0
28	**Makurdi TS**	**0.61286**	**-1.0608**	**-2.6547**	**-1.1946**
29	Egbin GS	1.0	0	15.1641	5.9032
30	**New Heaven TS**	**0.74694**	**-0.77106**	**-2.2565**	**-1.2776**
31	Okpai SS	0.96846	-0.54106	0	0
32	Alaoji SS	0.97449	-0.44856	0	0
33	Geregu SS	0.88899	-0.67922	0	0
34	Aladja TS	0.95446	-0.5798	-3.0197	-1.2776
35	**Ugwuaji TS**	**0.73874**	**-0.78035**	**-2.074**	**-1.1448**
36	Geregu GS	1.0	-0.56742	1.991	1.9835
37	Ihovbor GS	1.0	-0.13423	3.982	0.35109
38	Afam SS	0.9805	-0.43422	0	0
39	Ikot Ekpene TS	0.93647	-0.48663	-2.7376	-1.2278
40	Adiabor TS	0.97182	-0.43344	-1.4933	-0.7964
41	Odukpani SS	0.98586	-0.41291	0	0
42	Omotosho GS	1.0	-0.56784	3.1192	2.6841
43	Delta GS	1.012	-0.52795	4.6623	4.6927
44	Afam GS	1.003	-0.40181	4.6465	2.4611
45	Odukpani GS	1.0	-0.39293	4.3138	2.3911
46	Okpai GS	1.0	-0.51582	3.6668	3.6064
47	Alaoji GS	1.0	-0.42135	3.982	2.9262
48	Sapele GS	1.0	-0.40482	2.8208	0.46255

Table 3. Voltage stability sensitivity factor of the Nigerian 48-bus system for transient stability analysis

BUS NO	BUS NAME	VOLTAGE STABILITY SENSITIVITY FACTOR
1	Kainji GS	0.00000
2	Kainji SS	0.04828
3	Jebba TS	0.08373
4	Jebba SS	0.08000
5	Shiroro SS	0.17175
6	Oshogbo TS	0.09782
7	Ayede TS	0.09460
8	Ikeja West TS	0.11234
9	Ihovbor SS	0.07570
10	Ganmo TS	0.09727
11	Kaduna TS	0.29798
12	Katampe TS	0.22449
13	Gwagwalada TS	0.21899
14	Olorunsogo SS	0.06823
15	Jebba GS	0.00000
16	Egbin SS	0.09414
17	Omotosho SS	0.21388
18	Okearo TS	0.10604
19	Benin TS	0.09946
20	Shiroro GS	0.00000
21	**Jos TS**	**0.45519**
22	Lokoja TS	0.19812
23	Olorunsogo GS	0.00000
24	Onitsha TS	0.10838
25	Ajaokuta TS	0.18088
26	Delta SS	0.04215
27	Sapele SS	0.07217
28	Makurdi TS	0.39104
29	Egbin GS	0.00000
30	New Heaven TS	0.24153
31	Okpai SS	0.03684
32	Alaoji SS	0.02415
33	Geregu SS	0.09663
34	Aladja TS	0.05524
35	Ugwuaji TS	0.25072
36	Geregu GS	0.00000
37	Ihovbor GS	0.00000
38	Afam SS	0.01775
39	Ikot Ekpene TS	0.05458
40	Adiabor TS	0.01546
41	Odukpani SS	0.00283
42	Omotosho GS	0.00000
43	Delta GS	0.00000
44	Afam GS	0.00000
45	Odukpani GS	0.00000
46	Okpai GS	0.00000
47	Alaoji GS	0.00000
48	Sapele GS	0.00000

D. Power Flow Simulation with SVC

Figures 11-14 display the rotor angle, rotor speed, voltage magnitude profile and real power responses of generator 6 without and with the installation of SVC at bus 21(Jos) in the system after the application of fault at bus 33.

V. DISCUSSIONS

Without fault in Figures 3-6, there was no disturbance hence, the system was relatively stable. This is depicted in all the graphs appearing in straight lines. The rotor angle of the different generators in p.u. plotted against time as shown in Figure 3 came out as straight lines to indicate a situation of no perturbation, hence a state of stability. The same can be said of the rotor speed (Figure 4) which has all the generators in synchronism having the same speed of 1 p.u. The various voltage levels of all the 48 buses which as observed falls within the acceptable voltage limit of 0.95 to 1.05 p.u. shows a stable state without any form of disturbances hence, their straight-line form (Figure 5), while Figure 6 depicts the generators real power responses which also came out as straight lines indicating stability of the system

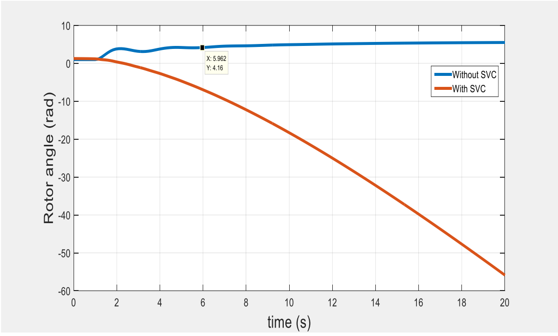

Figure 11. Generator 6 rotor angle Response without and with SVC

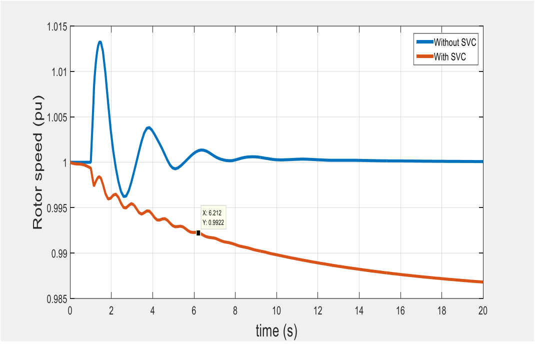

Figure 12. Generator 6 rotor speed response without and with SVC

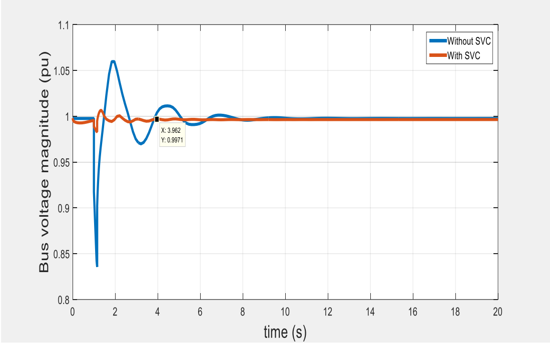

Figure 13. Generator 6 Voltage magnitude Profile without and with SVC

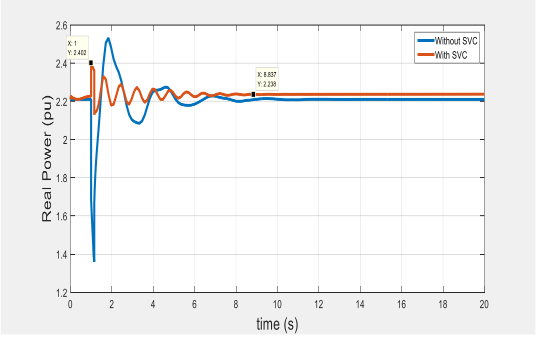

Figure 14. Generator 6 real power responses without and with SVC

Simulations with application of fault are displayed in Figures 7-10. Figure 7 illustrates the rotors angle behaviour for the fourteen synchronous generators which kept increasing until they go out of synchronism thereby loosing stability. The rotors speed which settled to steady state condition after 11.34s and whose amplitudes of swing is observed to rise up to 1.015 p.u. depending on the proximity of the generator to the fault is shown in Figure 8. Figure 9 shows the voltage magnitude profile plot of all the 48 buses. Without SVC device, the amplitude of swing is high up to 1.093 which exceeds the allowable voltage limit of 1.05. The frequency of oscillation is also high as the swing dampened out at 11.21s. This portrays a high level of instability in the system. Figure 10 displays the real power responses of the 14 generators in the network. Taking the responses of generators 9 and 11 for example, it can be noted that the post fault oscillation settled out at 13.71s and 9.587s respectively. The amplitude of oscillation should also be noted that while that of generator 9 stands at 0.518 p.u., that of generator 11 was 0.544 p.u. The high settling time and amplitude of oscillation indicates the level of instability in the system.

Taking generator 6 as an example, Figures 11-14 display the comparison of the responses of the system when SVC is optimally installed after the application of fault. The rotor angle response is displayed in Figure 11. With fault applied, the rotor angle is observed to rise slightly before damping out after 5.962s. But at the application of SVC, the rotor angle decreases gradually indicating the returning back of the system to marginal stability. Figure 12 depicts the comparison of the generator 6 rotor speed with and without SVC where the post fault settling time with SVC is seen to be 6.212s while without SVC, the settling time was 11.71s. It can also be observed that the frequency of oscillation is less with SVC which oscillates about its reference value compared to that without SVC which rose up to 1.013 p.u. For the voltage magnitude profile for generator 6 as displayed in Figure 13, the post fault oscillation damped out after 3.962s with SVC applied while it damped out after 9.964s without SVC. The system with SVC is also seen not to exhibit any overshoot but it oscillates about 1.0 p.u. before dampening out. The real power response of Figure 14 shows the post fault oscillation damping out at about 8.837s with the application of SVC as against 9.962s without SVC. The amplitude of swing with SVC is seen to shoot up to 0.202 p.u. compared with 0.332 p.u. without SVC.

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