American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-9, Issue-6, pp-177-184
www.ajer.org
Research Paper Open Access

Increasing the Transient Stability of Benin Bus in the Nigerian 330kv Transmission System Using Proportional Integral Based VSC-HVDC Method

ANAZIA A. E[1], OKOLO C. C[2], EZEUGBOR I. C[3],ASOGWA E. C[3], UDUH E. J[1]

[1]DEPARTMENT OF ELECTRICAL ENGINEERING, NNAMDI AZIKIWE UNIVERSITY, AWKA, ANAMBRA STATE
[2]ELCTRONICS DEVELOPMENT INSTITUTE, FEDERAL MIN. OF SCIENCE AND TECHNOLOGY AWKA CAPITAL TERRITORY, ANAMBRA STATE
[3]DEPARTMENT OF COMPUTER SCIENCE, NNAMDI AZIKIWE UNIVERSITY, AWKA, ANAMBRA STATE

ABSTRACT: *This paper presents the application of Voltage Source Converter – High Voltage Direct Current (VSC-HVDC) controlled by the conventional proportional integral (PI) method for the enhancement of the transient stability of Nigerian 330kV transmission system. PSAT environment was used to model Nigerian 330kV transmission network. The system load flow was also simulated. The critical buses were determined with an analysis on the eigenvalue and damping ratio of the network. The current transient stability situation of the grid was established by observing the dynamic responses of the generators in the network when a balanced three-phase fault was applied to some of these critical buses and transmission lines. It was realized thatthe Benin bus and Ikeja West – Benin Transmission lineare critical within the network. It was also realized through the load flow analysis that the system loses synchronism when the balanced three-phase fault was applied. This confirms Nigeria 330-kV transmission network critical and requires urgent measures to control itin other to improve the stability margin of the network thereby avoiding a system collapse. To this effect, VSC-HVDC was installed along to those critical lines. MATLAB/PSAT software was employed as the tool for the simulations. Also when compared with the results without HVDC, there is transient stability improvement.*

KEYWORD: Transient Stability, voltage, Transmission line, HVDC, Proportional Integral

---

Date of Submission: 07-06-2020 Date of acceptance: 22-06-2020

I. INTRODUCTION

This paperconfirms an enhancement in the dynamic response of generators within a power system, when a fault is introduced. This has been a great challenge to power system engineers for a long time. A lot of works done by other authors as regards to transient stability improvement of power transmission network using FACTS devices such as UPFC, STATCOM, HVDC etc. have been exhaustively reviewed. The review showed that VSC-HVDC modulation could lead to substantial improvement in transient stability. But it could be noted that the critical clearing times CCT obtained in past works were small and therefore there are still room for further improvement. Hence, in this work efforts would be made to increase the CCT of fault. The ability of the Nigerian 330kVpower system to maintain synchronism after a sudden large disturbance has been a major issue that will be addressed in this work.

II. MATERIALS AND METHODS

MATLAB/PSAT software was employed as the tool for the simulations. The existing Nigerian 330kV transmission system was modelled in PSAT environment and the system load flow was simulated. The eigenvalue analysis of the system buses PSAT environment was used to model Nigerian 330kV transmission network. The system load flow was also simulated. The critical buses were determined with an analysis on the eigenvalue and damping ratio of the network. The current transient stability situation of the grid was established by observing the dynamic responses of the generators in the network when a balanced three-phase fault was applied to some of these critical buses and transmission lines. It was realized that the Benin bus and Ikeja West – Benin Transmission line are critical within the network. It was also realized through the load flow analysis that the system loses synchronism when the balanced three-phase fault was applied. To this effect, VSC-HVDC was installed along to this critical line. The inverter and the converter parameters of the HVDC were controlled by the conventional proportional integral (PI) method

Power Flow Analysis of Nigeria 330kv Transmission Power System

The Nigeria 330-kV transmission network used as the case study in this dissertation is shown in Figure 1. It consists of eleven (11) generators, twenty-nine (29) loads, comprising of forty (40) buses and fifty-two (52) transmission lines, which cut across the six (6) Geopolitical zone (South-West, South-South, South-East, North-Central, North-West and North-East Region) of the country with long radial interconnected transmission lines.The line diagram and data of the Nigerian transmission system were sourced from the National Control Centre of Power Holding Company of Nigeria, Osogbo, Nigeria. Power flow analysis of the Nigerian transmission system was performed in Matlab/Psat environment as shown in Figure 1.

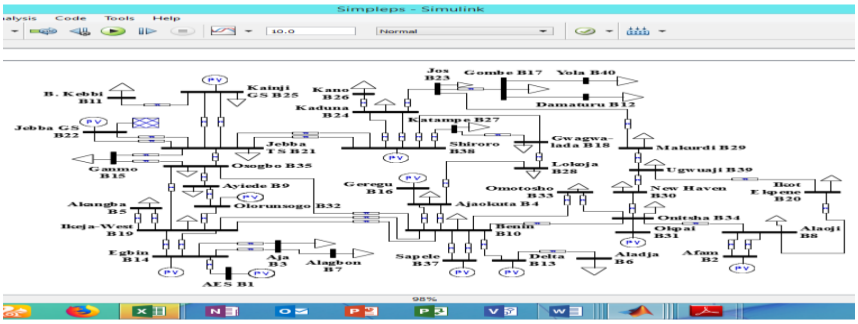

Figure 1PSAT Model of the Nigeria 330kV transmission power system without VSC-HVDC

Figure 1 shows the PSAT modelling of the existing Nigerian 330kV transmission grid with existing system parameters as obtained from the National Control Centre. The modelling was done without the inclusion of the VSC-HVDC system. Load flow analysis was performed on the model so as to establish the current stability situation, whether there is need for its transient stability improvement or not.

Mathematical Formulation of Swing Equation for a Multi- Machine Power System

When a multi-machine *n*-bus power network consisting of *m* number of generators is put into consideration such that *n* >*m* at any bus *I* within the system. The complex voltages (V_i), the generator reactive power (Q_{gi}) and generators real power (P_{gi}) can be obtained from the pre-fault load-flow analysis. The initial machine voltages(E_i) can also be obtained from this analysis. This relationship of the above mentioned can be

$$E_i = V_i + jX_i \left[\frac{P_{gi} - jQ_{gi}}{V_i^*}\right] \qquad (1,0)$$

Where;

X_i is the equivalent reactance at bus i. By converting each load bus into its equivalent constant admittance form, we have

$$Y_{Li} = \frac{P_{Li} - jQ_{Li}}{|V_i|^2} \qquad (1.1)$$

Where $P_{Li}$and $Q_{Li}$are the respective equivalent real and reactive powers at each load buses. The pre-fault bus admittance matrix [*bus Y*] can therefore be formed with the inclusion of generators reactance and the converted load admittance. This can be partitioned as

$$Y_{bus} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \qquad (1.2)$$

Where Y_{11}, Y_{12}, Y_{21}, and Y_{22} are the sub-matrices of Y_{bus}. Out of these four sub-matrices, Y_{11}, whose dimension is $m \times m$is the main interest of this work as it contains generators buses only with the load buses eliminated. The *bus Y* for the network is then formulated by eliminating all nodes except the internal generator nodes. The reduction is achieved based on the fact that injections at all load nodes are zero. The nodal equations, in compact form, can therefore be expressed as

$$\begin{bmatrix}1\\0\end{bmatrix} = \begin{bmatrix}Y_{mm} & Y_{mn}\\ Y_{nm} & Y_{nn}\end{bmatrix}\begin{bmatrix}V_m\\ V_n\end{bmatrix} \quad (1.3)$$

By expansion equation (3.20) can be expanded as

$$I_m = Y_{mm}V_m + Y_{mn}V_n \quad (1.4)$$

and $$0 = Y_{mm}V_m + Y_{mn}V_n \quad (1.5)$$

By combining equations (3.21) and (3.22) and some mathematical manipulations, the desired reduced admittance matrix can be obtained as

$$Y_{reduced} = Y_{mm} - Y_{mn}Y_{nn}^{-1}Y_{nm} \quad (1.6)$$

$Y_{reduced}$ is the desired reduced matrix with dimension m x m, where m is the number of generators. The electrical power output of each machine can then be written as

$$P_{ei} = E_i^2 Y_{ii}\cos\theta_{ii} + \sum_{\substack{i=1\\ j\neq 1}}^{m} |E_i||E_j||Y_{ij}|\cos\left(\theta_{ij} - \delta_i + \delta_j\right) \quad (1.7)$$

Equation (3.24) is then used to determine the system during fault $P_{ei}(P_{ei(during\,-fault)})$ and post-fault $P_{ei}(P_{ei(post\,-fault)})$ conditions.

The rotor dynamics, representing the swing equation, at any bus *i*, is given by

$$\frac{H_i}{\pi f_0}\frac{d^2\delta_i}{dt^2} + D_i\frac{d_i}{dt} = P_{mi} - P_{ei} \quad (1.8)$$

All the parameters retain their usual meanings.

Consider a case when there is no damping i.e. $D_i = 0$, equation (3.25) can be re-written as

$$\frac{H_i}{\pi f_0}\frac{d^2\delta_i}{dt^2} = P_{mi} - \left(E_i^2 Y_{ii}\cos\theta_{ii} + \sum_{\substack{i=1\\ j\neq 1}}^{m} |E_i||E_j||Y_{ij}|\cos\left(\theta_{ij} - \delta_i + \delta_j\right)\right) \quad (1.9)$$

The swing equation for the during-fault condition can easily be expressed as

$$\frac{H_i}{\pi f_0}\frac{d^2\delta_i}{dt^2} + D_i\frac{d_i}{dt} = P_{mi} - P_{ei(during\,-fault)} \quad (2.0)$$

Similarly, the swing equation for the post fault condition can be written as

$$\frac{H_i}{\pi f_0}\frac{d^2\delta_i}{dt^2} + D_i\frac{d_i}{dt} = P_{mi} - P_{ei(post\,-fault)} \quad (2.1)$$

Table 1: Extracted output from eigenvalue analysis

Bus Number	Bus Name	Eigen Value (γ)	Damping Ratio (τ)	Participation Factor (%)
1	AES	$2.7653 \pm j\,8.4192$	0.6442	1.0520
2	Afam	$-1.9404 \pm j\,4.2813$	0.4723	0.6197
3	Aja	$-2.1746 \pm j\,6.7011$	0.2632	0.7139
4	Ajaokuta	$1.9640 \pm j\,3.1032$	0.0476	2.6122
5	Akangba	$2.0367 \pm j\,8.2287$	0.5941	0.6122
6	Aladja	$-3.4083 \pm j\,6.0053$	0.7456	2.4165
7	Alagbon	$0.2562 \pm j\,5.7324$	0.6745	0.4165
8	Alaoji	$-0.4528 \pm j\,4.2183$	0.6259	1.0817
9	Ayiede	$-2.7653 \pm j\,11.2419$	0.4933	0.3021
10	Benin	$2.8730 \pm j\,6.1437$	0.0219	3.3021
11	Brenin Kebbi	$-2.1674 \pm j\,5.1101$	1.3511	0.3228
12	Damaturu	$1.6064 \pm j\,6.8320$	0.8232	3.1297
13	Delta	$-2.0367 \pm j\,8.2287$	0.7624	1.1096
14	Egbin	$3.4083 \pm j\,7.1537$	0.8320	0.3176
l15	Ganmo	$-0.2562 \pm j\,5.7324$	0.8031	0.2113
16	Geregui	$-0.4528 \pm j\,4.2183$	0.2803	0.2113
17	Gombe	$-4.6097 \pm j\,7.5635$	2.3893	0.3260
18	Gwagwa	$2.3576 \pm j\,8.1273$	0.3048	1.0640
19	Ikeja-West	$-0.5284 \pm j\,3.3182$	1.1601	0.2639
20	Ikot Ekpene	$4.6097 \pm j\,7.3637$	0.5060	0.2680

21	Jebba TS	$-1.7356 \pm j\,4.9214$	0.0931	4.6422
22	Jebba GS	$-1.7653 \pm j\,10.4192$	0.1311	0.1422
23	Jos	$1.4011 \pm j3.1375$	0.6534	0.3252
24	Kaduna	$-2.1746 \pm j\,6.7011$	0.7324	1.9180
25	Kainji GS	$-1.9640 \pm j\,5.3208$	0.6612	1.2912
26	Kano	$2.5376 \pm j\,10.9419$	0.3342	1.0768
27	Katampe	$-1.7011 \pm j\,3.1375$	0.3442	0.0768
28	Lokoja	$-2.1746 \pm j\,6.7011$	0.2632	0.7139
29	Makurdi	$3.0640 \pm j\,5.3208$	0.0564	2.6122
30	New Haven	$2.0367 \pm j\,8.2287$	0.5941	0.6122
31	Okpai	$-3.4083 \pm j\,7.5374$	0.7456	5.4165
32	Olorunsogo	$-0.2562 \pm j\,4.7324$	0.2674	3.4165
33	Omotosho	$2.7297 \pm j\,5.5635$	0.3284	4.2720
34	Onitsha	$0.4528 \pm j\,4.2183$	0.6259	0.1817
35	Osogbo	$-3.8372 \pm j\,6.3756$	0.1842	4.3366
36	Papalanto	$-2.7653 \pm j\,11.2419$	0.4933	0.3021
37	Sapele	$1.7301 \pm j\,3.1375$	0.2193	3.3021
38	Shiroro	$0.1674 \pm j\,4.1170$	0.0925	6.3228
39	Ugwuaji	$-1.6064 \pm j\,6.8320$	0.8232	3.1297
40	Yola	$-2.0367 \pm j\,8.2287$	1.7624	1.1096

From the tabulation, it can be seen that the Nigeria 330kV transmission grid network is generally not stable. This is due to the fact that all the eigenvalues are not located on the left side of the S-plane. The Eigenvalues located on the left side of the S-plane are negative whereas eigenvalues located on the right side of the S-plane are positive.

Installation of VSC-HVDC to the Nigeria 40 Bus 330kv Transmission Network for Transient Stability Improvement during Occurrence of a Three-Phase Fault

Figures 2 shows the PSAT Model of the Nigeria 330kV transmission power system with VSC-HVDC transmission line installed along side with Benin – Ikeja West, transmission lines respectively. The choice of position for the location of the VSC-HVDC was determined through eigenvalue analysis as its eigenvalue was located on the right side of the S-plane and also is among the three buses that have the lowest damping ratio (as aforementioned). Here, Load flow analysis was performed on the model with bus 10 (Benin) subjected to a three phase faults whereas the loads at other buses were held constant at the demand values. This is as to establish the stability situation, whether there is improvement in the transient stability improvement.

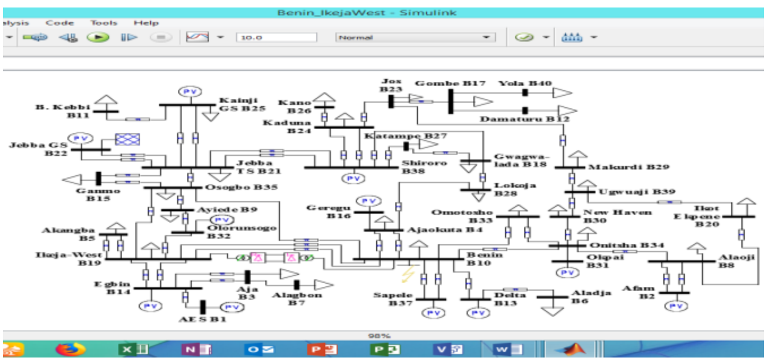

Figure 2:PSAT Model of the Nigeria 330kV transmission power system with VSC-HVDC installed along side with Ikeja West- Benin Transmission Line

III. RESULTS

Response of the Nigeria 40 Bus 330kv Transmission Network to Occurrence of a Three-Phase Fault

A three-phase fault was created on Benin bus (Bus 10) with line Benin – Ikeja West (10- 19) removed by the circuit breakers (CBs) at both ends opening to remove the faulted line from the system. Figures 3 and 4 shows the dynamics responses of the generators for CCT of 350ms.

Figures 3 and 4 shows the plot of the power angle curves and the frequency responses of the eleven generators in the system during a transient three-phase fault on Benin to Ikeja West transmission line. It can be observed that virtually all generators in the system at were critically disturbed and all failed to recover after the was cleared at 0.35 seconds. So, the system lost synchronism and became unstable as shown in Figures 3 and 4.

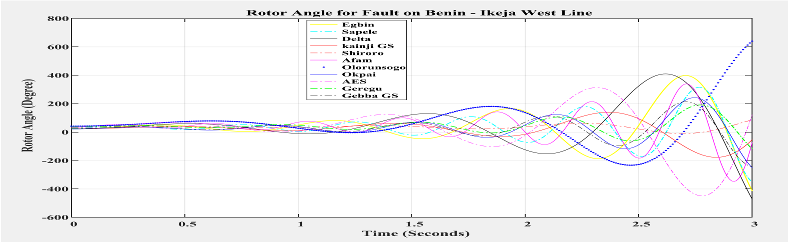

Figure 3: Rotor Angle response of the generators for fault clearing time of 0.35 sec without any VSC-HVDC

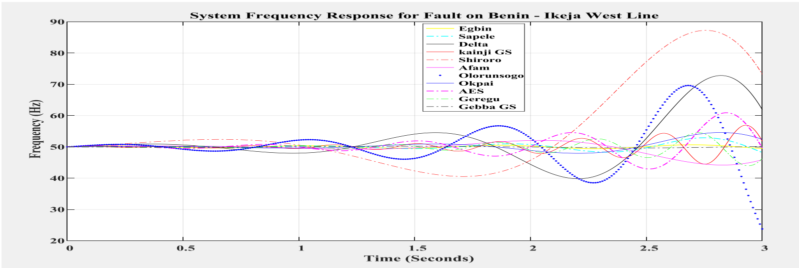

Figure 4: Frequency response of the system generators for fault clearing time of 0.35 sec without any VSC-HVDC

Response of the Nigeria 330kv Transmission Grid to Occurrence of a Three-Phase Fault with Hvdc Installed in the Unstable Benin Bus

Here, a VSC-HVDC is being controlled by the convectional PI method and not by the artificial neural network. As aforementioned, the simulation results are carried out on the MATLAB/PSAT environment. The idea is to see the effect of the HVDC, acting as a typical FACTS device, on the transient stability of the system during occurrence of a three-phase transient fault and also on the bus voltage violations. **T**he location of the VSC-HDVC was changed to complement Benin – Ikeja West transmission line. Again, a three-phase fault was created on Benin bus (Bus 10) with line Benin – Ikeja West (10- 19) removed, by the circuit breakers (CBs) at both ends opening to remove the faulted line from the system. Figures 4 and 5 show the dynamics responses of the generators for CCT of 350ms.

Figures 5 and 6 show the plot of the power angle curves and the frequency responses of the eleven generators in the system during a transient three-phase fault on Benin to Ikeja West transmission line. It can be observed that all the generators in the system which were critically disturbed and failed to recover after the fault was cleared at 0.35 seconds during a fault occurrence without VSC-HVDC in the system, are all stable. This again, is attributed to the fact that the VSC-HVDC was able to inject enough power in the two buses (Bus 10 - 19). Hence, with the HVDC in that position the transient stability of the system has been improved as can be seen from the plot of the frequency and the power angle of the system generators in Figures 4 and 5 respectively.

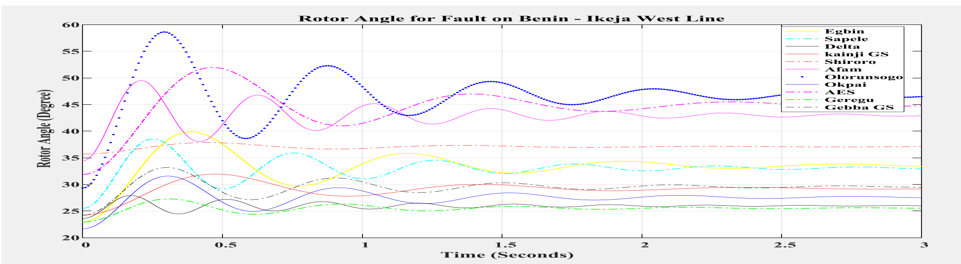

Figure 5: Power Angle response of the generators for fault clearing time of 0.35 sec with only VSC-HVDC

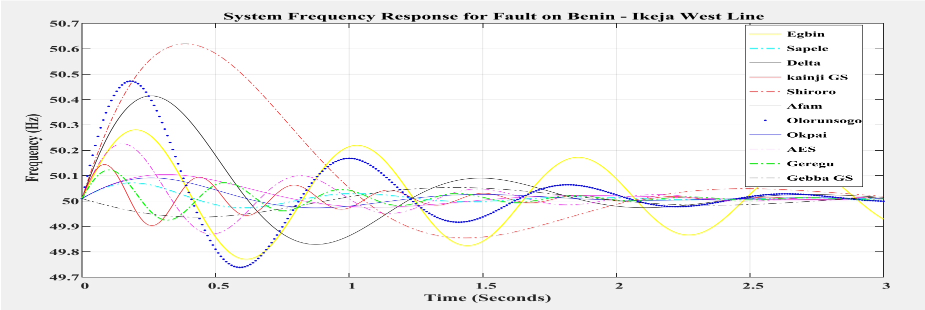

Figure 6: Frequency response of the system generators for fault clearing time of 0.35 sec with only VSC-HVDC

The voltage profile results of the Nigerian 40-bus 330kV transmission system with VSC-HVDC installed between Benin to Ikeja West bus after the occurrence of the fault are shown in Table 2 as obtained from the power flow analysis of the network in PSAT environment. It can be observed from Table 2 and Figure 7 that the voltage magnitudes at the bus voltages are now within the acceptable voltage limit of ±10% for the Nigerian 330kV transmission system. This is as result of the reactive power capability of the HVDC.

Table 2: The Simulated Bus Voltage Profile during Occurrence of a Three Phase Fault on Benin Bus with VSC-HVDC Installed

Bus No	Bus Name	Voltage [p.u.]	Phase Angle [rad]
1	AES	0.930561	0.016368
2	Afam	0.905654	-0.00533
3	Aja	0.998480	0.006284
4	Ajaokuta	0.989621	-0.00676
5	Akangba	0.980541	-0.10014
6	Aladja	0.996952	-0.00231
7	Alagbon	0.984200	-0.03763
8	Alaoji	1.000000	-0.00962
9	Ayiede	0.936654	0.001761
10	Benin	0.995594	-0.00382
11	B. Kebbi	0.912544	-0.04433
12	Damaturu	0.996001	0.001354
13	Delta	0.934967	0.000672
14	Egbin	0.929967	0.007773
15	Ganmo	0.995887	-0.00372
16	Geregu	0.989101	-0.00231
17	Gombe	0.976632	-0.04365
18	Gwagwa-lada	0.953375	-0.03592
19	Ikeja-West	0.996943	0.001354
20	Ikot Ekpene	0.988973	-0.01895
21	Jebba TS	0.999967	0
22	Jebba GS	0.999967	0.00215
23	Jos	0.926433	-0.04046
24	Kaduna	0.971423	-0.03687
25	Kainji GS	1.000000	0.007816
26	Kano	0.982557	-0.20071
27	Katampe	0.973536	-0.03586
28	Lokoja	0.970445	-0.03763
29	Makurdi	0.972167	-0.03443

30	New Haven	0.985259	-0.01984
31	Okpai	0.998001	-0.03763
32	Olorunsogo	0.983565	0.61537
33	Omotosho	0.928672	-0.72907
34	Onitsha	0.907250	-0.01132
35	Osogbo	0.994828	-0.00446
36	Papalanto	0.963279	-0.04365
37	Sapele	0.920670	-0.00019
38	Shiroro	0.998189	-0.90286
39	Ugwuaji	0.981078	-0.02538
40	Yola	0.939224	-0.04763

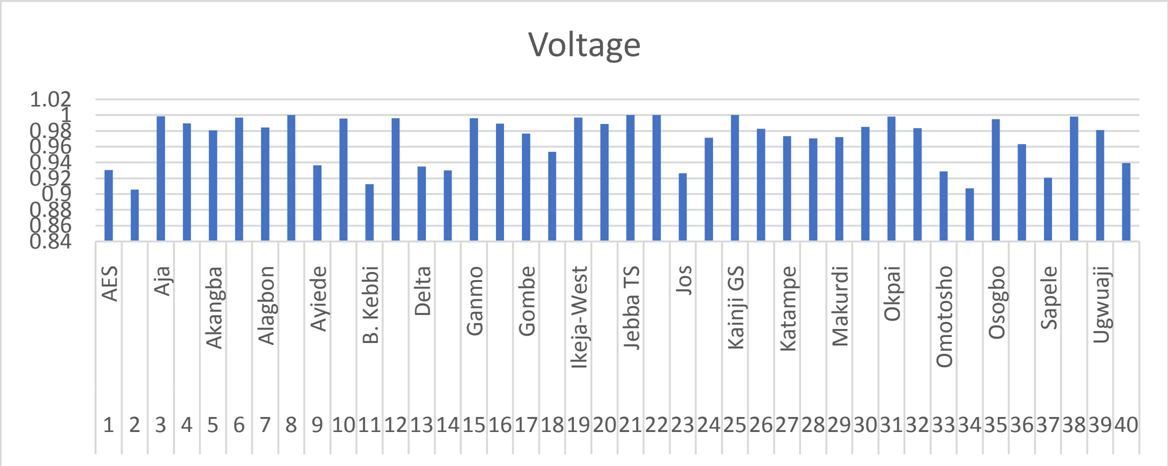

Figure 7: Nigeria 330kV Transmission Line Bus Voltage Profile during Occurrence of a Three Phase Fault on Benin Bus with VSC-HVDC Installed

The voltage profile results of the Nigerian 40-bus 330kV transmission system with PI Controlled VSC-HVDC installed between Benin to Ikeja West bus after the occurrence of the fault observed that the voltage violations at buses 1, 2, 13, and 37 were improved to 0.930561,0.905654,0.922923 and 0.920670. Finally, the imminent system collapse of the Nigeria 330kV transmission network as a result of the system being on a red-alert has been mitigated by this dissertation.

IV. CONCLUSION

In this work, transient stability improvement of the Nigeria 330-kV grid system using intelligent VSC-HVDC has been carried out. The mathematical formulations for the analysis are presented. The location of a balanced 3-phase fault, at various nodes, was determined based on the most critical buses within the network which was determined through eigenvalue analysis and damping ratio. The dynamic responses for various fault locations are obtained. The results obtained show that the Nigeria 330-kV transmission network is presently operating on a time-bomb alert state which could lead to total blackout if a 3-phase fault occurs on some strategic buses. The result obtained shows that when a 3-phase fault of any duration occurs on Benin bus, the system losses synchronism immediately. Also Ajaokuta – Benin transmission lines have been identified as a critical line that can excite instability in the power network if removed to clear a 3-phase fault.

REFRENCES

[1]. Abido M. A. (2009). Power system enhancement using FACTS controllers: A review. The Arabian Journal for Science and Engineering, Vol.34, No.1B, pp.153–172.

[2]. Abikhanova G., Ahmetbekova A., Bayat E., Donbaeva A., Burkitbay G. (2018). International motifs and plots in the Kazakh epics in China (on the materials of the Kazakh epics in China), Opción, Año 33, No. 85. 20-43.

[3]. Adepoju G. A., Komolafe, O. A, Aborisade, D.O. (2011). Power Flow Analysis of the Nigerian Transmission System Incorporating Facts Controllers. International Journal of Applied Science and Technology Vol. 1 No. 5; September 2011

[4]. Haykin, S. (1994). Neural Networks: A comprehensive foundation. Macmillan Collage Publishing Company, Inc., New York.

[5]. Ignatius K. O., Emmanuel A. O. (2017). Transient Stability Analysis of the Nigeria 330-kV Transmission Network. American Journal of Electrical Power and Energy Systems 2017; 6(6): 79-87,http://www.sciencepublishinggroup.com/j/epes, doi: 10.11648/j.epes.20170606.11; ISSN: 2326-912X (Print); ISSN: 2326-9200 (Online)
[6]. Izuegbunem F. I., Ubah C. B. and Akwukwaegbu I. O. (2012). Dynamic security assessment of 330kV Nigeria power system. Academic Research International Journal, pp. 456- 466.
[7]. Karthikeyan K. and Dhal P. K. (2015). Transient Stability Enhancement by Optimal location and tuning of STATCOM using PSO. Smart and Grid Technologies (ELSEVEIR), pp. 340-351.
[8]. Rani, A. and Arul, P. (2013). Transient Stability Enhancement of Multi-Machine Power System Using UPFC and SSSC. International Journal of Innovative Technology and Exploring Engineering, 3, 77-81.
[9]. Roberto R. J. P. and Charpentier R. S. (2000). High Voltage Direct Current (HVDC) Transmission Systems Technology Review Paper. Presented at Energy Week 2000, Washington, D.C, USA, March 7-8, 2000
[10]. Sachidananda D. (2019). Methods of improving stability. https://electricalshouters.com/methods-of-improving-stability/
[11]. Vasilic, S., and Kezunovic, M. (2004). Fuzzy ART Neural Network Algorithm for Classifying the Power System Faults. IEEE Transactions on Power Delivery, pp 1-9.
[12]. Vittal and Vijay. (2007). Direct Stability Methods. https://circuitglobe.commm/different-types-hvdc-links.html
[13]. Zhou Y., Huang H., Xu Z., Hua W., Yang F. and Liu S. (2015). Wide area measurement system-based transient excitation boosting control to improve power system transient stability. IET Generation, Transmission & Distribution, Vol.9, No.9, pp.845–854.

ANAZIA A. E, et. al. "Increasing the Transient Stability of Benin Bus in the Nigerian 330kv Transmission System Using Proportional Integral Based VSC-HVDC Method." *American Journal of Engineering Research (AJER)*, vol. 9(06), 2020, pp. 177-184.