https://dx.doi.org/10.22161/ijaems.62.5 ISSN: 2454-1311

Improving Transient Stability of the Nigerian 330kv Transmission System on Ajaokuta - Benin Transmission Line with the help of artificial Neural Network (ANN) based VSC high Voltage direct current method

Okolo C. C[1], Ezechukwu O. A[2], Enemuo F. O[2], Anazia A. E[2], Onuegbu J. O[2]

[1]Electronics Development Institute, Federal Ministry of Science and Technology, Awka Capital Territory, Anambra state, Nigeria
[2]Department of Electrical Engineering, Nnamdi Azikiwe University, Awka, Anambra state, Nigeria

***Abstract*— *Enhancement of the dynamic response of generators, within a power system, when subjected to various disturbances, has been a major challenge to power system researchers and engineers for the past decades. This work presents the application of intelligent Voltage Source Converter – High Voltage Direct Current (VSC-HVDC) for improvement of the transient stability of the Nigeria 330kV transmission system which is used as the case study network in this work. First, the current transient stability situation of the grid was established by observing the dynamic response of the generators in the Nigeria 330-kV grid/network when a balanced three-phase fault was applied to some critical buses and lines of the transmission network. These critical buses were determined through the eigenvalue analysis of the system buses. The result obtained clearly show that there exist critical buses such as Ajaokuta and critical transmission line such Ajaokuta - Benin Transmission line within the network. The results also revealed that the system losses synchronism when a balanced three-phase fault was applied to these identified critical buses and lines. The results further indicated that the Nigeria 330-kV transmission network is on a red-alert, which requires urgent control measures with the aim of enhancing the stability margin of the network to avoid system collapse. To this effect, VSC-HVDC was installed in addition to those critical lines. The inverter and the converter parameters of the HVDC were controlled by the artificial neural network. The results obtained showed that 42.86% transient stability improvement was achieved when the HVDC was controlled with the artificial neural network when compared to the PI controllers in the Nigeria 330-kV grid/network.*

***Keywords*— buses, converter, stability, transient, transmission.**

I. INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Nowadays, the demand of electricity has radically increased and a modern power system becomes a difficult network of transmission lines interconnecting the generating stations to the major loads centers in the overall power system in order to support the high demand of consumers. Transmission networks being overloaded, are pushed closer to their stability limits. This is as a result of increasing demand for electricity due to growing population. This could have negative effect on the power system security. The complicated network causes the stability problem. Stability is determined by the observation of voltage frequency and rotor angle. One of the indices in assessing the state of security of a power system is the transient stability. This also involves the ability of power system to remain in equilibrium or return to acceptable equilibrium when subjected to large disturbances (Ayodele, Jimoh, Munda and Agee, 2012). Transient stability examines the impact of disturbance of power systems considering the operating conditions. The analysis of the dynamic behavior of power systems for the transient stability give information about the ability of power system to sustain synchronism during and after the disturbances.

https://dx.doi.org/10.22161/ijaems.62.5 ISSN: 2454-1311

II. LITERATURE REVIEW

2.1 POWER FLOW ANALYSIS NIGERIA 330KV TRANSMISSION POWER SYSTEM

The Nigeria 330-kV transmission network is used as the case study in this work. 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

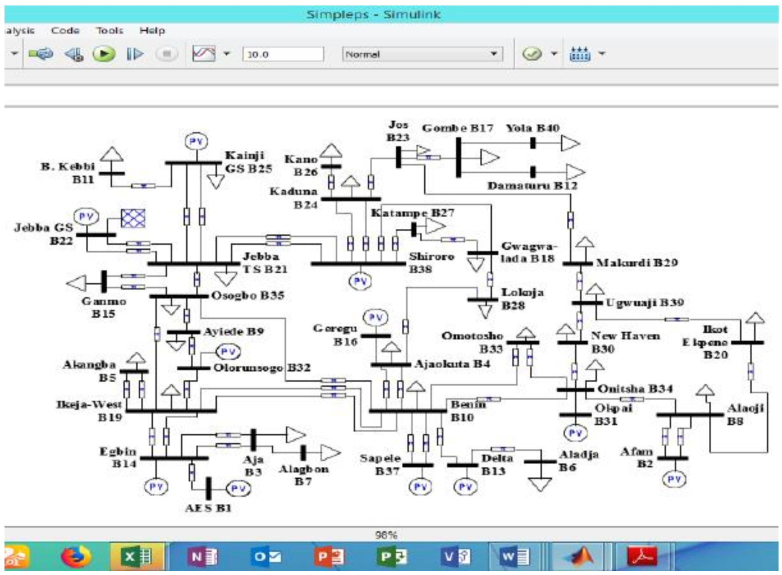

Fig.1.0: PSAT Model of the Nigeria 330kV transmission power system without VSC-HVDC

III. METHODOLOGY

3.1 EIGENVALUE ANALYSIS

The Eigenvalue analysis investigates the dynamic behavior of a power system under different characteristic frequencies (''modes''). In a power system, it is required that all modes are stable. Moreover, it is desired that all electromechanical oscillations are damped out as quickly as possible. The Eigen value (γ) gives information about the proximity of the system to instability. The participation factor measures the participation of a state variable in a certain mode oscillation. The damping ratio (τ) is an indication of the ability of the system to return to stable state in the event of disturbance. The output from the eigenvalue analysis on the Psat model of the Nigeria 330kV transmission grid is extracted and tabulated in Table 1.0 To ensure that the buses to be used are marginally unstable, the buses selected are buses having eigenvalue that lie on the right side of the S-plane and having lowest value of damping ratio.

Table 1.0 Extracted output from eigenvalue analysis

Bus Number	Bus Name	Eigen Value (γ)	Damping Ratio (τ)	Participation Factor (%)
1	AES	$2.7653 \pm j8.4192$	0.6442	1.0520
2	Afam	$-1.9404 \pm j4.2813$	0.4723	0.6197
3	Aja	$-2.1746 \pm j6.7011$	0.2632	0.7139
4	Ajaokuta	$1.9640 \pm j3.1032$	0.0476	2.6122
5	Akangba	$2.0367 \pm j8.2287$	0.5941	0.6122
6	Aladja	$-3.4083 \pm j6.0053$	0.7456	2.4165
7	Alagbon	$0.2562 \pm j5.7324$	0.6745	0.4165
8	Alaoji	$-0.4528 \pm j4.2183$	0.6259	1.0817

https://dx.doi.org/10.22161/ijaems.62.5 *ISSN: 2454-1311*

9	Ayiede	$-2.7653 \pm j11.2419$	0.4933	0.3021
10	Benin	$2.8730 \pm j6.1437$	0.0219	3.3021
11	BreninKebbi	$-2.1674 \pm j5.1101$	1.3511	0.3228
12	Damaturu	$1.6064 \pm j6.8320$	0.8232	3.1297
13	Delta	$-2.0367 \pm j8.2287$	0.7624	1.1096
14	Egbin	$3.4083 \pm j7.1537$	0.8320	0.3176
15	Ganmo	$-0.2562 \pm j5.7324$	0.8031	0.2113
16	Geregui	$-0.4528 \pm j4.2183$	0.2803	0.2113
17	Gombe	$-4.6097 \pm j7.5635$	2.3893	0.3260
18	Gwagwa	$2.3576 \pm j8.1273$	0.3048	1.0640
19	Ikeja-West	$-0.5284 \pm j3.3182$	1.1601	0.2639
20	IkotEkpene	$4.6097 \pm j7.3637$	0.5060	0.2680
21	Jebba TS	$-1.7356 \pm j4.9214$	0.0931	4.6422
22	Jebba GS	$-1.7653 \pm j10.4192$	0.1311	0.1422
23	Jos	$1.4011 \pm j3.1375$	0.6534	0.3252
24	Kaduna	$-2.1746 \pm j6.7011$	0.7324	1.9180
25	Kainji GS	$-1.9640 \pm j5.3208$	0.6612	1.2912
26	Kano	$2.5376 \pm j10.9419$	0.3342	1.0768
27	Katampe	$-1.7011 \pm j3.1375$	0.3442	0.0768
28	Lokoja	$-2.1746 \pm j6.7011$	0.2632	0.7139
29	Makurdi	$3.0640 \pm j5.3208$	0.0564	2.6122
30	New Haven	$2.0367 \pm j8.2287$	0.5941	0.6122
31	Okpai	$-3.4083 \pm j7.5374$	0.7456	5.4165
32	Olorunsogo	$-0.2562 \pm j4.7324$	0.2674	3.4165
33	Omotosho	$2.7297 \pm j5.5635$	0.3284	4.2720
34	Onitsha	$0.4528 \pm j4.2183$	0.6259	0.1817
35	Osogbo	$-3.8372 \pm j6.3756$	0.1842	4.3366
36	Papalanto	$-2.7653 \pm j11.2419$	0.4933	0.3021
37	Sapele	$1.7301 \pm j3.1375$	0.2193	3.3021
38	Shiroro	$0.1674 \pm j4.1170$	0.0925	6.3228
39	Ugwuaji	$-1.6064 \pm j6.8320$	0.8232	3.1297
40	Yola	$-2.0367 \pm j8.2287$	1.7624	1.1096

3.2: INSTALLATION OF VSC-HVDC TO THE NIGERIA 40 BUS 330KV TRANSMISSION NETWORK FOR TRANSIENT STABILITY IMPROVEMENT DURING OCCURRENCE OF A THREE-PHASE FAULT

Figures 2.0 show the PSAT Model of the Nigeria 330kV transmission power system with VSC-HVDC installed along side with Ajaokuta – Benin Transmission Line. The position for the location of the VSC-HVDC was determined through eigenvalue analysis as aforementioned. The demonstration for the transient stability improvement on the Nigeria 330-kV grid network, in this work, considered Ajaokuta – Benin Transmission Line.

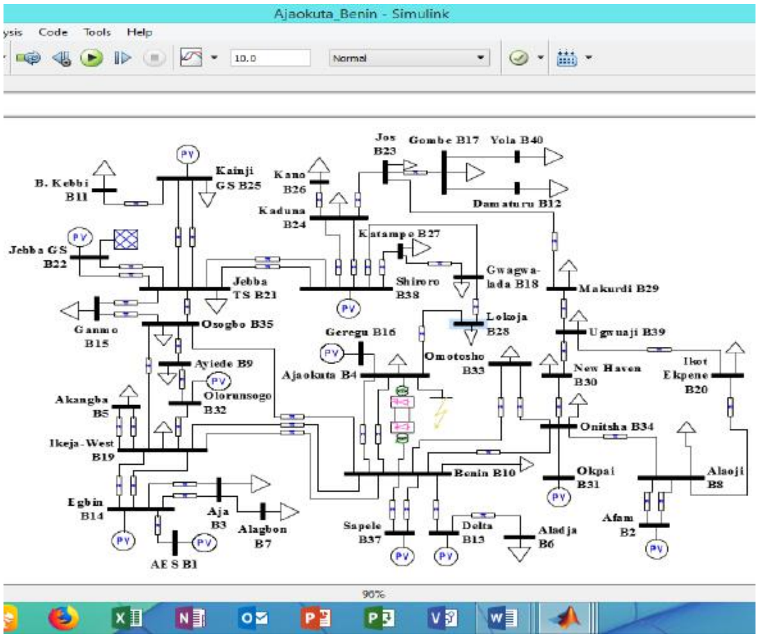

Fig.2.0: PSAT Model of the Nigeria 330kV transmission power system with VSC-HVDC installed along side with Ajaokuta – Benin Transmission Line

3.3 RESPONSE OF THE NIGERIA 330KV TRANSMISSION GRID TO OCCURRENCE OF A THREE-PHASE FAULT WITHOUT ANN CONTROLLED VSC-HVDC INSTALLED IN THE UNSTABLE BUSES

In this scenario, a three-phase fault was created on Ajaokuta bus (Bus 4) with line Benin – Benin (4-10) removed. Figures 3 and 4 shows the dynamics response of the generators for CCT of 300ms.Figures 3 and 4 shows the plot of the power angle curves and the frequency response of the eleven generators in the system during a transient three-phase fault on Ajaokuta to Benin transmission line. It can be observed that generators at Geregu, Sapele, Delta, Okpai and Afam buses were most critically disturbed and failed to recover after the fault was cleared at 0.35 seconds. These five generators in the system lost synchronism and became unstable as shown in Figures 3.0 and 4.0

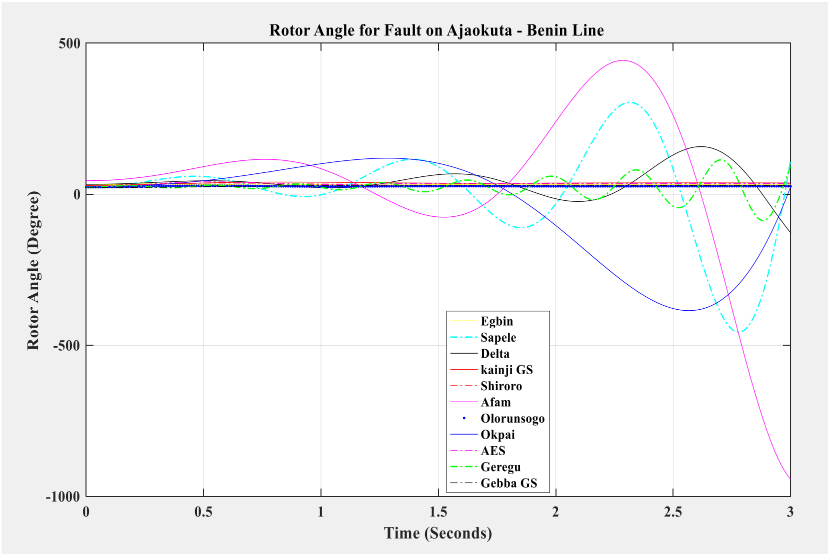

Fig.3.0: Rotor Angle response of the generators for fault clearing time of 0.35 sec without any VSC-HVDC

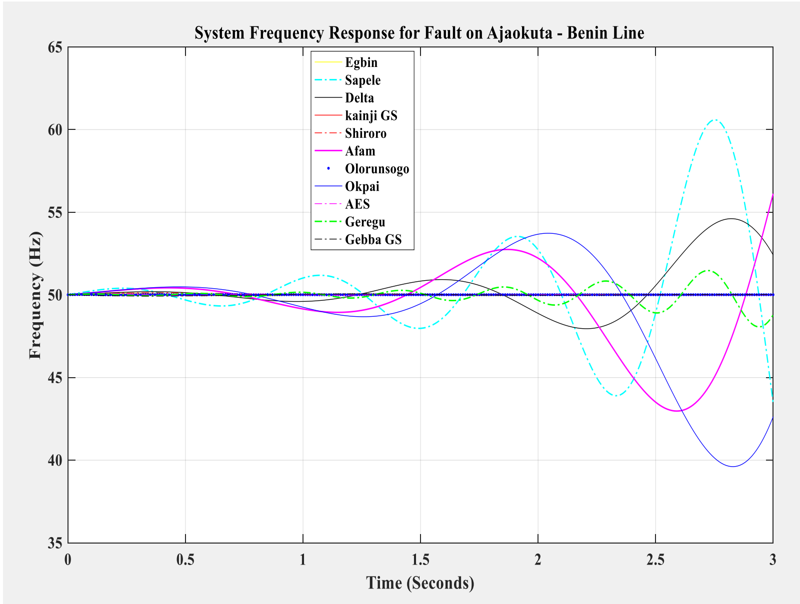

Fig.4.0: Frequency response of the system generators for fault clearing time of 0.35 sec without any VSC-HVDC

The voltage profile results of the Nigerian 40-bus 330kV transmission system after the occurrence of the fault are shown in Table 4.4 as obtained from the power flow analysis of the network in PSAT environment. It can be observed that there are serious voltage violations at buses 1 (AES), 2 (Afam), 13 (Delta), 16 (Geregu), 31 (Okpai), 32 (Olorunsogbo) and 37 (Sapele). The voltage magnitudes at these buses are lower than the acceptable voltage limit of ±10% for the Nigerian 330kV transmission system.

Table.2.0: The Simulated Bus Voltage Profile during Occurrence of a Three Phase Fault on Ajaokuta Bus

Bus No	Bus Name	Voltage [p.u.]	Phase Angle [rad]
1	AES	0.773990	0.02390
2	Afam	0.822780	-0.00125
3	Aja	0.998480	0.006284
4	Ajaokuta	0.989621	-0.00676
5	Akangba	0.805418	-0.10014
6	Aladja	0.996952	-0.00231
7	Alagbon	0.842001	-0.03763
8	Alaoji	1.000000	-0.00962
9	Ayiede	0.996654	0.001761
10	Benin	0.995594	-0.00382
11	B. Kebbi	0.955445	-0.04433
12	Damaturu	0.996001	0.001354
13	Delta	0.821045	0.000607
14	Egbin	1.000000	0.007773
15	Ganmo	0.995887	-0.00372
16	Geregu	0.798931	-0.00382
17	Gombe	0.766327	-0.04365

18	Gwagwa-lada	0.853375	-0.03592
19	Ikeja-West	0.996943	0.001354
20	IkotEkpene	0.988973	-0.01895
21	Jebba TS	1.000000	0
22	Jebba GS	1.000000	0.00215
23	Jos	0.966434	-0.04046
24	Kaduna	0.971423	-0.03687
25	Kainji GS	1.000000	0.007816
26	Kano	0.825577	-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	0.816998	-0.00953
32	Olorunsogo	0.783557	0.04615
33	Omotosho	0.772546	-0.72907
34	Onitsha	0.992507	-0.01132
35	Osogbo	0.994828	-0.00446
36	Papalanto	0.963277	-0.04365
37	Sapele	0.873953	-0.00113
38	Shiroro	0.818990	-0.90286
39	Ugwuaji	0.981078	-0.02538
40	Yola	0.995245	-0.04763

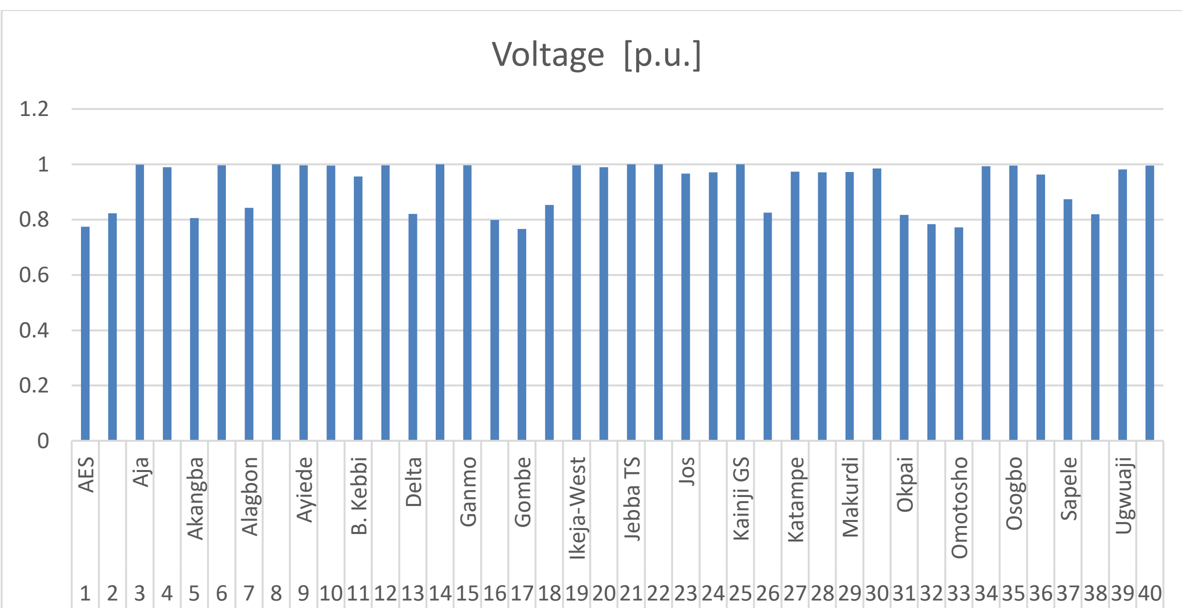

Fig.5.0 Nigeria 330kV Transmission Line Bus Voltage Profile During Occurrence of a Three Phase Fault on Ajaokuta Bus

https://dx.doi.org/10.22161/ijaems.62.5 ISSN: 2454-1311

3.4 RESPONSE OF THE NIGERIA 330KV TRANSMISSION GRID TO OCCURRENCE OF A THREE-PHASE FAULT WITH ANN CONTROLLED VSC-HVDC INSTALLED IN THE UNSTABLE BUSES

Here, artificial neural network was used to regulate and control the parameters of the rectifier and the inverter of the VSC-HVDC instead of the convectional PI method. The idea is to see the effect of the HVDC, whose parameters are being controlled by neural network, on the transient stability of the system during occurrence of a three-phase transient fault and also on the bus voltage violations.The numerical solver, ode45, which is a built-in MATLAB function, is employed in solving the *m*-number of swing equations within the system. The CCT for the phase fault has been improved from 350ms to 500ms resulting to a 42.86% increment.When the position of the ANN controlled VSC-HDVC was atAjaokuta – Benin transmission line, a three-phase fault was created on Ajaokuta bus (Bus 4) with line Ajaokuta – Benin (4-10) removed by the CBs at both ends opening to remove the faulted line from the system. Figures 6.0 and 7.0show 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 Ajaokuta to Benin transmission line. It can be observed that the oscillation of those five generators at Geregu, Sapele, Delta, Okpai and Afam buses which were most critically disturbed during a fault occurrence without VSC-HVDC, along with other generators, have achieved faster damping. It can also be noted that the CCT has been increased from 350 milli-seconds to 500 milli-seconds and also the oscillations were quickly damped.This can be attributed to the intelligent response of the neural network in controlling the parameters of the VSC-HVDC, which enabled to inject the needed power in the two buses (Bus 4 – 10) in time and most appropriately. Hence, from Figures 6.0 and 7.0, the transient stability of the system has been further improved with the intelligent HVDC in the system.

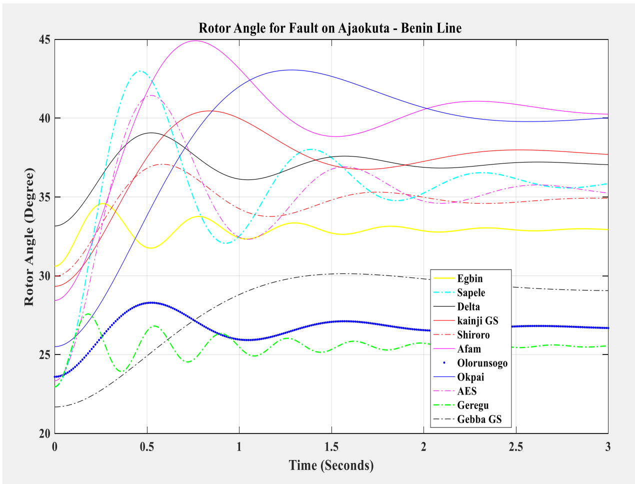

Fig.6.0: Rotor Angle response of the generators for fault clearing time of 0.5 sec with ANN Controlled VSC-HVDC

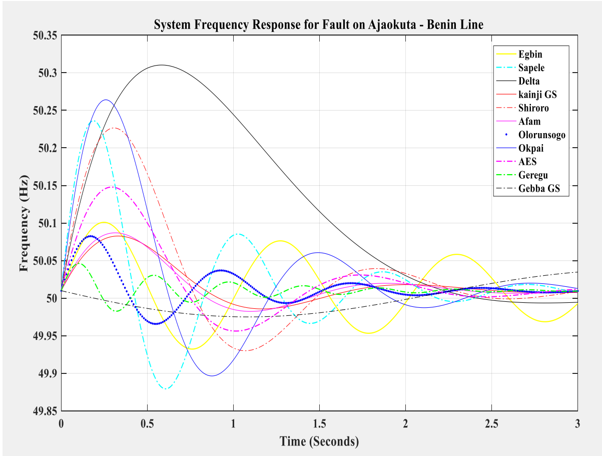

Fig.7.0: Frequency response of the system generators for fault clearing time of 0.5 sec with ANN Controlled VSC-HVDC

https://dx.doi.org/10.22161/ijaems.62.5 ISSN: 2454-1311

The voltage profile results of the Nigerian 40-bus 330kV transmission system with ANN Controlled VSC-HVDC installed between Ajaokuta to Benin bus after the occurrence of the fault are shown in Table 2.0 as obtained from the power flow analysis of the network in PSAT environment. It can be observed from Table 2.0 and Figure 5.0 that the voltage violations at buses 1, 2, 13, 16, 31, 32 and 37 which were 0.905738, 0.909903, 0.922923, 0.919679, 0.941849, 0.919188 and 0.960770 as obtained previously when the VSC-HVDC was being controlled by the conventional PI method are now improved to 0.998421,1.000000, 0.999275, 0.979914, 0.997805, 0.998835 and 1.000000 respectively. This is as result of the intelligent response of the VSC-HVDC in injecting adequate reactive power timely.

Table.3.0: The Simulated Bus Voltage Profile during Occurrence of a Three Phase Fault on Ajaokuta Bus with ANN Controlled VSC-HVDC Installed

Bus No	Bus Name	Voltage [p.u.]	Phase Angle [rad]
1	AES	0.998421	0.02336
2	Afam	1.000000	-0.01134
3	Aja	0.998480	0.006284
4	Ajaokuta	0.989621	-0.00676
5	Akangba	0.805418	-0.10014
6	Aladja	0.996952	-0.00231
7	Alagbon	0.842001	-0.03763
8	Alaoji	1	-0.00962
9	Ayiede	0.996654	0.001761
10	Benin	0.995594	-0.00382
11	B. Kebbi	0.955445	-0.04433
12	Damaturu	0.996001	0.001354
13	Delta	0.999275	0.00146
14	Egbin	1.000000	0.007773
15	Ganmo	0.995887	-0.00372
16	Geregu	0.979914	-0.00953
17	Gombe	0.766327	-0.04365
18	Gwagwa-lada	0.853375	-0.03592
19	Ikeja-West	0.996943	0.001354
20	IkotEkpene	0.988973	-0.01895
21	Jebba TS	1.000000	0
22	Jebba GS	1.000000	0.00215
23	Jos	0.966434	-0.04046
24	Kaduna	0.971423	-0.03687
25	Kainji GS	1.000000	0.007816
26	Kano	0.825577	-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	0.997805	-0.05617
32	Olorunsogo	0.998835	0.05615
33	Omotosho	0.772546	-0.72907
34	Onitsha	0.992507	-0.01132
35	Osogbo	0.994828	-0.00446
36	Papalanto	0.963277	-0.04365
37	Sapele	1.000000	-0.00380
38	Shiroro	0.818990	-0.90286
39	Ugwuaji	0.981078	-0.02538
40	Yola	0.995245	-0.04763

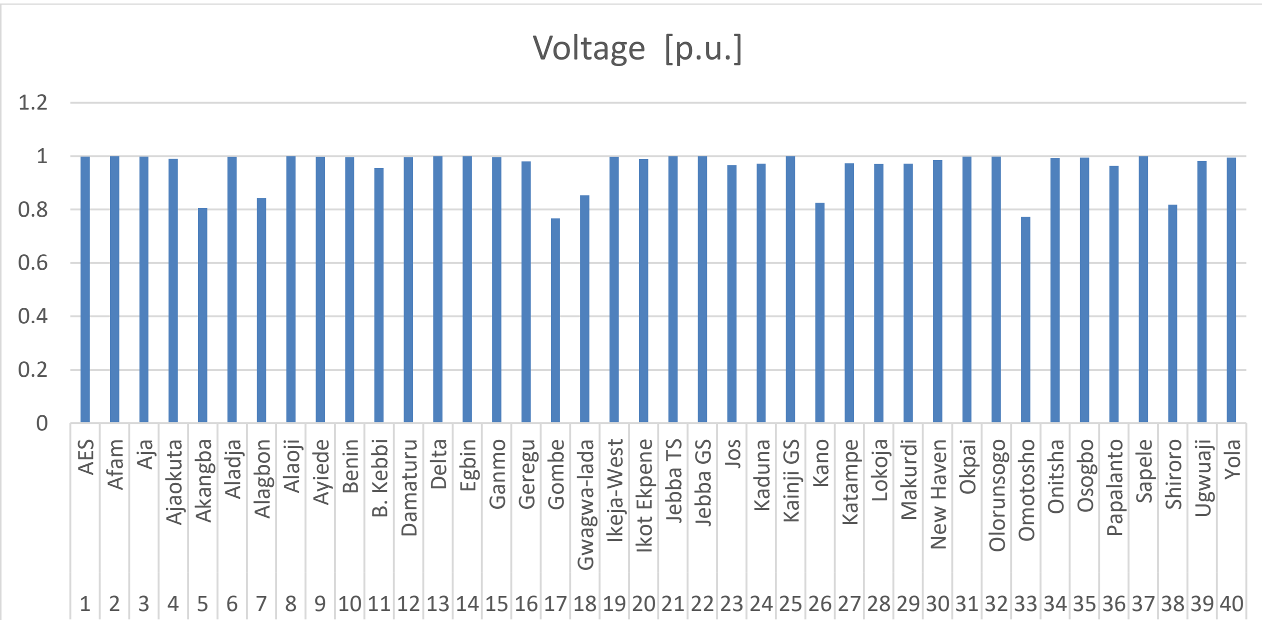

Fig.8.0: Nigeria 330kV Transmission Line Bus Voltage Profile during Occurrence of a Three Phase Fault on Ajaokuta Bus with ANN Controlled VSC-HVDC Installed

IV. CONCLUSION

In this work, transient stability improvement of the Nigeria 330-kV grid system using intelligent VSC-HVDC has been carried out. 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. 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 Ajaokuta bus, the system losses synchronism immediately. The 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. The results obtained showed that greater transient stability was achieved when the HVDC was controlled with the artificial neural network as can be seen by observing the dynamic response of the generators in the Nigeria 330-kV grid network. The entire simulation of the Nigeria 330kV transmission network was done in MATLAB/PSAT environment.

REFERENCES

[1] Abikhanova G., Ahmetbekova A., Bayat E., Donbaeva A., Burkitbay G. (2018). International motifs and plots in the

https://dx.doi.org/10.22161/ijaems.62.5 *ISSN: 2454-1311*

Kazakh epics in China (on the materials of the Kazakh epics in China), Opción, Año 33, No. 85. 20-43.

[2] 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*

[3] Ayodele T R, Jimoh A A, Munda J L, and Agee J T, (2012).Challenges of grid integration of wind power on power system grid integrity.A review. International Journal of Renewable Energy Research, 2, 618-626

[4] Ayodele T R, Jimoh A. A., Munda J. L., and Agee J T, (2012). The impact of wind power on power system transient stability based on probabilistic weighting method. Journal of Renewable and Sustainable Energy, 4, 1-18.

[5] Ayodele T R, Jimoh A A, Munda J L, and Agee J T, (2012).Challenges of grid integration of wind power on power system grid integrity.A review. International Journal of Renewable Energy Research, 2, 618-626

[6] Ayodele T R, Jimoh A. A., Munda J. L., and Agee J T, (2012). The impact of wind power on power system transient stability based on probabilistic weighting method. Journal of Renewable and Sustainable Energy, 4, 1-18.

[7] Bompard E., Fulli G., Ardelean M. and Masera M. (2014). It's a Bird, It's a Plane, It's a... Supergrid. *IEEE power & energy magazine*, Vol.12, No.2, pp.41–50.

[8] Chettih, S., M. Khiat and A. Chaker, (2008).Optimal distribution of the reactive power and voltages control in Algerian network using the genetic algorithm method. Inform. Technol. J., 7: 1170-1175. DOI: 10.3923/itj.2008.1170.1175

[9] EseosaO., and Onahaebi S. O. (2015). Optimal location of IPFC in Nigeria 330kV Integrated Power Network using GA Technique. Journal of Electrical and Electronics Systems, pp. 1-8.

[10] Fuchs A., Imhof M., Demiray T. and Morari M. (2014).Stabilization of Large Power Systems Using VSC HVDC and Model Predictive Control.*IEEE Transactions on Power Systems*, Vol.29, No.1, pp.480–488.

[11] Oluseyi P. O., Adelaja T. S., and Akinbulire T. O. (2017).Analysis of the Transient Stability Limit of Nigeria's 330kV Transmission sub-network. Nigeria Journal of Technology, pp. 213-226.

[12] Parry, M. and N. Gangatharan, (2005).Adaptive data transmission in multimedia networks. Am. J. Applied Sci., 2: 730-733. DOI: 10.3844/ajassp.2005.730.733

[13] Sharma P. R. and Hooda, (2012). Transient Stability Analysis of Power System using MATLAB. International Journal of Engineering Sciences and Research Technology, pp. 418-422, 2012.

[14] Sidhu, T.S., Singh, H. and Sachdev, M.S. (2005).*Design, implementation and testing of an artificial neural network based fault direction discriminator for protecting transmission lines.* IEEE Trans. On Power Delivery, vol. 10, no., pp 697-706.

[15] Vasilic, S., and Kezunovic, M. (2004).Fuzzy *ART Neural Network Algorithm for Classifying the Power System Fault*s. IEEE Transactions on Power Delivery, pp 1-9.

[16] Vittal and Vijay.(2007). Direct Stability Methods. https://circuitglobe.commm/different-types-hvdc-links.html

[17] 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.