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Improving the Transient Stability of Ajaokuta Bus in the Nigerian 330KV Transmission System Using Proportional Integral Based VSC-HVDC Method

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Abstract- Improvement of the dynamic response of generators, within a power system, with the existence of various disturbances, has been a very serious challenge to the power system engineers and researchers. The application of intelligent Voltage Source Converter – High Voltage Direct Current (VSC-HVDC) to enhance the transient stability of Nigerian 330kV transmission system was studied. PSAT environment was used to model Nigerian 330kV transmission network. The simulation of the system load flow was done. By obtaining the eigenvalue and damping ratio from the eigenvalue analysis of the system buses, one of the critical buses and transmission lines were determine. A balanced three-phase fault is hereby introduced in these critical buses and transmission lines of the network to obtain the current transient stability situation of the grid. This was achieved through what was obtained from the dynamic responses of the generators in Nigeria 330-kV grid/network at the point of introducing the fault. This shows clearly that one of the most critical buses is Ajaokuta bus and critical transmission line is Ajaokuta-Benin Transmission line within the network. The load flow analysis also shows that the system loses synchronism when the balanced three-phase fault was applied to these identified critical buses and lines. This implies that Nigeria 330-kV transmission network is on a bad state and requires urgent control measures with the aim of enhancing the stability margin of the network to avoid system collapse. The VSC-HVDC installation was done along to the critical line. The conventional PI method was used to control the parameters from the converter and inverter of the High Voltage Direct Current. MATLAB/PSAT software was used as the tool to do the simulations. When it was compared with the results of other similar, there was transient stability improvement. The obtained results showed that there is transient stability improvement when the PI controlled HVDC was installed. When compared with the results of other similar works of 28.57% transient stability improvement, it was observed through the dynamic response observed from the generators in the Nigeria 330-kV grid/network.

Keyword - Transient, Stability, Integral, Transmission, HVDC

I. INTRODUCTION

The security of a power system is regarded as the ability of the network to withstand disturbances without breaking down [2].The complicated network causes the stability problem. Stability is determined by the observation of voltage frequency and rotor angle. One of the indices to assess the security condition of a power system is the transient stability. It involves the ability of power system to maintain its equilibrium state or return to acceptable equilibrium at the point large disturbances are introduced [3]. Recently, the electricity demand has increased so much and a modern power system becomes a difficult network of transmission lines which interconnects the generating stations to the major loads centers in the overall power system. This is to support the high demand by the consumers. When the transmission networks are overloaded, it is pushed closer to its stability limits. The transient signal is one of the causes of instability. Transients happen when we witness a sudden voltage or current change in a power system. Due to the complexity and dynamic nature of the power system conditions and configurations, power system stability is always difficult to achieve. As individual, we all depend on electricity to help in our activities which includes: heating, cooling, and lightning of our homes, refrigerate and prepare our food, pump and purify our water, handle sewage and support most of our hospital, communication and entertainment. As a society also, we depend on electrical energy to light our streets, control the flow of traffic on the road, rails and in the air, operate the myriad physical and information supply chain that create, produce and distribute goods and services, maintain public safety and help to assure our national security. Installation of the HVDC system to the critical Ajaokuta bus in the test case network and then perform load flow on the entire system during occurrence of a three-phase fault. Application of intelligent VSC-HVDC to enhance transient stability of Nigerian 330kV transmission system using the proportional integral method with regards to Ajaokuta bus is presented in this paper.

II. RELATED WORK

The main components of an electric power system are generation, transmission and distribution systems. The generating and distribution systems are connected through transmission lines. Transmission lines normally imply the bulk transfer of power by high-voltage links between main load centers [1]. A reactive-power supplementary signal was provided for each converter. When the power produced by generators that lost synchronism is controlled, there will be a primary improvement in the system stability and also automatically disconnecting some power consumers. The issue here is that the VSC-HVDC design was not implemented on any 330kV transmission network as proposed in this dissertation.

III. MEHODOLOGY

The tool employed for the simulations of this work was MATLAB/PSAT software. The PSAT environment was used to model the Nigerian 330kV transmission system. The simulation of system load flow was also done. To obtain the critical buses of the system, the eigenvalue and damping ratio was obtained. This identified the Ajaokuta bus and Ajaokuta - Benin transmission line among others as a critical bus and transmission line. A balanced three-phase fault was introduced in the above mentioned critical bus and transmission line to obtain the present transient stability situation of the grid. It was identified from the load flow analysis performed that the system losses synchronism during the introduction of the faults to the identified critical bus and line. The Voltage Source Converter - HVDC was hereby installed along to this aforementioned transmission line (Ajaokuta - Benin transmission line). The PI method was used in the control of the inverter and converter parameters of the HVDC.

ANALYSIS OF THE POWER FLOW OF NIGERIA 330KV TRANSMISSION POWER SYSTEM

Nigeria 330-kV transmission network which is the case study in this dissertation. Its consists of the following; 11 generators, comprising of 40 buses, 52 transmission lines and 29 loads which exist within 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.

National Control Centre of Power Holding Company of Nigeria, Osogbo, Nigeria provided the line diagram and data of the Nigerian transmission system. Matlab/Psat environment was used to perform THE Power flow analysis of the Nigerian transmission system as shown in Figure 1.

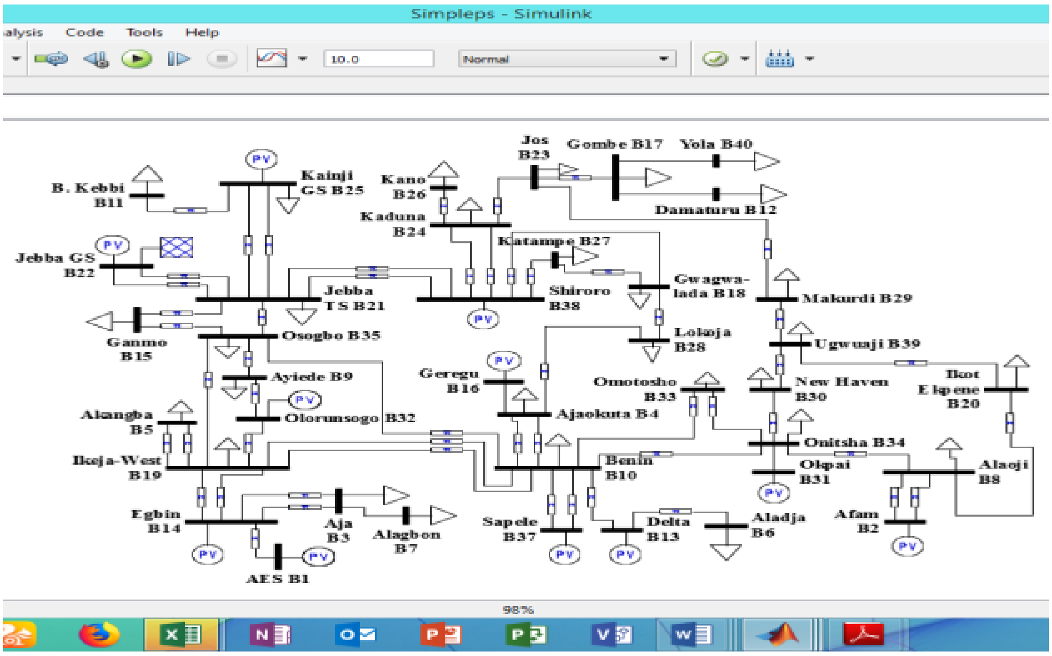

Figure 1: Nigeria 330kV transmission power system PSAT Model (without VSC-HVDC)

The present Nigerian 330kV transmission network with the system parameters as obtained from the National Control Centre shows its PSAT model in figure 1.

THE SWING EQUATION MATHEMATICAL FORMULATION FOR A MULTI- MACHINE POWER SYSTEM

The consideration of a multi-machine n-bus power grid which consists of m number of generators in a way that $n > m$. The complex voltages (V_i), generators real power (P_{gi}) and the generator reactive power (Q_{gi}) can be easily achieved from the pre-fault load-flow analysis from which the initial machine voltages(E_i) can still be achieved at any bus I within the system. The above relationship can be expressed as follows,

$$E_i = V_i + jX_i\left[\frac{P_{gi}-jQ_{gi}}{V_i^*}\right] \qquad (1.0)$$

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} is the equivalent real and $Q_{Li}$is the reactive powers at each load buses respectively. With the inclusion of generators reactance and the converted load admittance, the pre-fault bus admittance matrix [*bus Y*] can be formed. It can also be partitioned as

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

Where the sub-matrices of Y_{bus} are Y_{11}, Y_{12}, Y_{21}, and Y_{22}. Out of these 4 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. Equation (1.2) is for the pre-fault, post-fault and during fault network conditions. By eliminating all nodes in the exception of the internal generator nodes, the *bus Y* for the network is formulated. Since the injections at all load nodes are zero, the reduction is achieved based on that. The nodal equations, in compact form, can therefore be expressed as

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

By expansion equation (1.3) can be expanded as

$$I_m = Y_{mm}V_m + Y_{mn}V_n \tag{1.4}$$

and $$0 = Y_{mm}V_m + Y_{mn}V_n \tag{1.5}$$

By combining equations (1.4) and (1.5) and some mathematical manipulations, the desired reduced admittance matrix can be obtained as

$$Y_{reduced} = Y_{mm} - Y_{mn}Y_{nn}^{-1}Y_{nm} \tag{1.6}$$

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

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

Equation (1.7) 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, which represents the swing equation, at any bus *i*, is

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

The usual meaning of the parameters were retained.

Consider a case without damping i.e. $D_i = 0$, equation (1.8) can also be re-written as

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

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

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

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

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

IV. EIGENVALUE ANALYSIS

The Eigenvalue analysis observes the dynamic behavior of the power system under different characteristic frequencies (‘‘modes’’). In a power system, it is required that all modes are stable. Moreover, it is expected that all electromechanical oscillations are damped out as quickly as possible. The Eigen value ($\boldsymbol{\gamma}$) gives information about the proximity of the system to instability. The damping ratio (τ) shows the possibility of the system to return to stable state at the introduction of disturbance.

Table 1: Extracted output from eigenvalue analysis

Bus Number	**Bus Name**	**Eigen Value ($\boldsymbol{\gamma}$)**	**Damping Ratio ($\boldsymbol{\tau}$)**	**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
9	Ayiede	$-2.7653 \pm j11.2419$	0.4933	0.3021
10	Benin	$2.8730 \pm j6.1437$	0.0219	3.3021
11	Brenin Kebbi	$-2.1674 \pm j5.1101$	1.3511	0.3228
12	Damaturu	$1.6064 \pm j6.8320$	0.8232	3.1297
13	Delta	$-2.0367 \pm \square 8.2287$	0.7624	1.1096
14	Egbin	$3.4083 \pm \square 7.1537$	0.8320	0.3176
l15	Ganmo	$-0.2562 \pm \square 5.7324$	0.8031	0.2113
16	Geregui	$-0.4528 \pm \square 4.2183$	0.2803	0.2113
17	Gombe	$-4.6097 \pm \square 7.5635$	2.3893	0.3260
18	Gwagwa	$2.3576 \pm \square 8.1273$	0.3048	1.0640
19	Ikeja-West	$-0.5284 \pm \square 3.3182$	1.1601	0.2639
20	Ikot Ekpene	$4.6097 \pm \square 7.3637$	0.5060	0.2680
21	Jebba TS	$-1.7356 \pm \square 4.9214$	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	$-3.8372 \pm \square 6.3756$	0.1842	4.3366
36	Papalanto	$-2.7653 \pm \square 11.2419$	0.4933	0.3021
37	Sapele	$1.7301 \pm \square 3.1375$	0.2193	3.3021
38	Shiroro	$0.1674 \pm \square 4.1170$	0.0925	6.3228
39	Ugwuaji	$-1.6064 \pm \square 6.8320$	0.8232	3.1297
40	Yola	$-2.0367 \pm \square 8.2287$	1.7624	1.1096

From the table above, it can be observed that the Nigeria 330kV transmission grid is not generally stable. This is due to the fact that all the eigenvalues are not located on the left side of the S-plane.

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 VSC-HVDC transmission line installed along side with Ajaokuta – Benin, transmission line in the Nigeria 330kV transmission power system. The decision on the position where the VSC-HVDC will be located was obtained through the eigenvalue analysis. A three phase balanced faults was introduced in bus 4 (Ajaokuta) whereas the other buses were kept constant at the demand values then Load flow analysis was performed. This is done to establish the transient stability improvement.

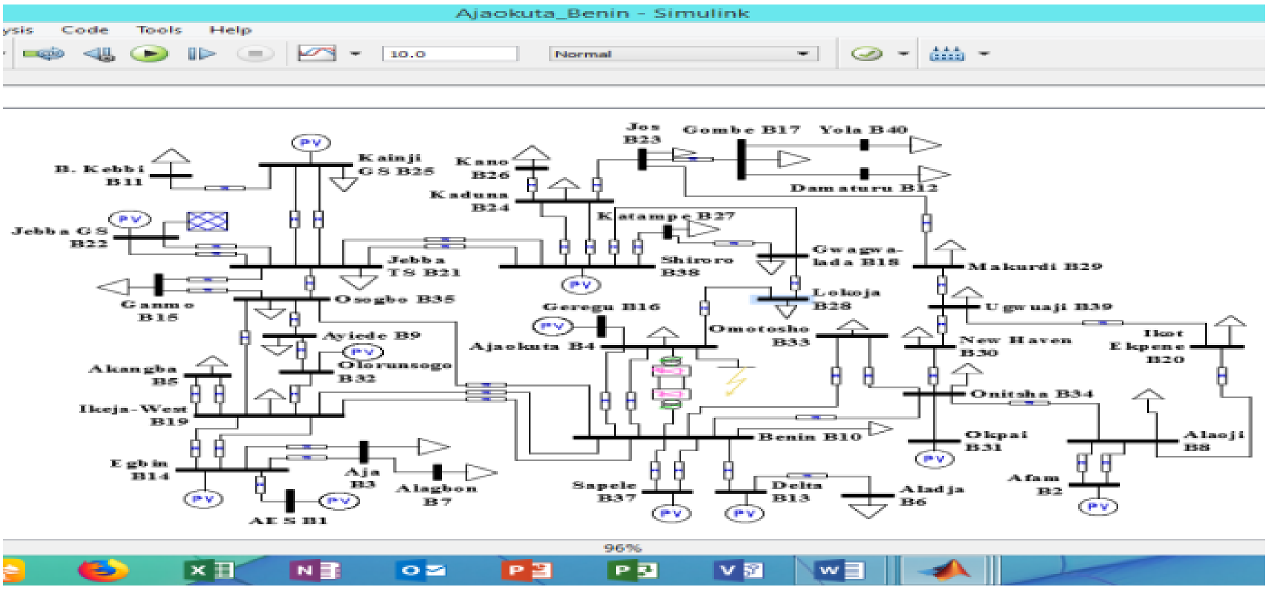

Figure 2: PSAT Model of the VSC-HVDC installed along side with Ajaokuta – Benin Transmission Line in Nigeria 330kV transmission power system with

V. RESULTS AND DISCUSSION

DYNAMICS RESPONSE AND VOLTAGE PROFILE OF THE EXISTING NIGERIA 40 BUS 330KV TRANSMISSION NETWORK TO OCCURRENCE OF A THREE-PHASE FAULT AT AJAOKUTA BUS

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 responses of the generators for CCT of 300ms. They 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 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 and 4.

After the existence of the fault, the voltage profile results of the system are shown in Table 2 as given from the PSAT environment enabled power flow analysis of the network. It can be observed from Table 2 and Figure 5 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.

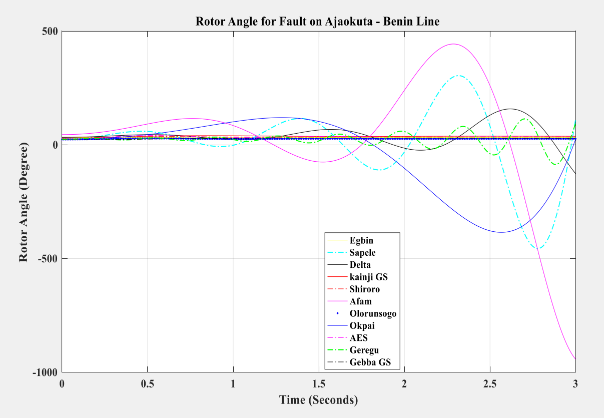

Figure 3: Rotor Angle response for the generators at fault clearing time of 0.35 sec (without VSC-HVDC)

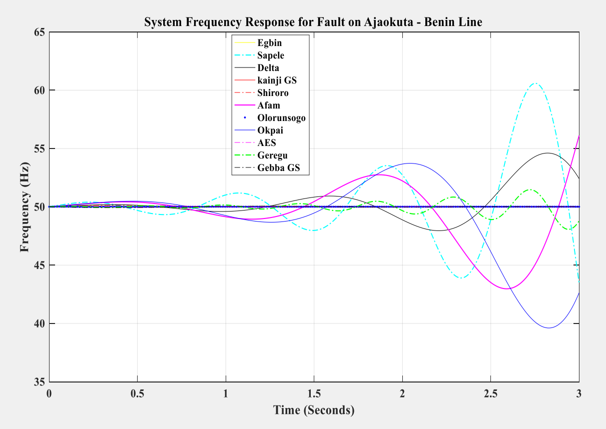

Figure 4: Frequency response for the system generators at fault clearing time of 0.35 sec (without VSC-HVDC)

Table 2: 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	Ikot Ekpene	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

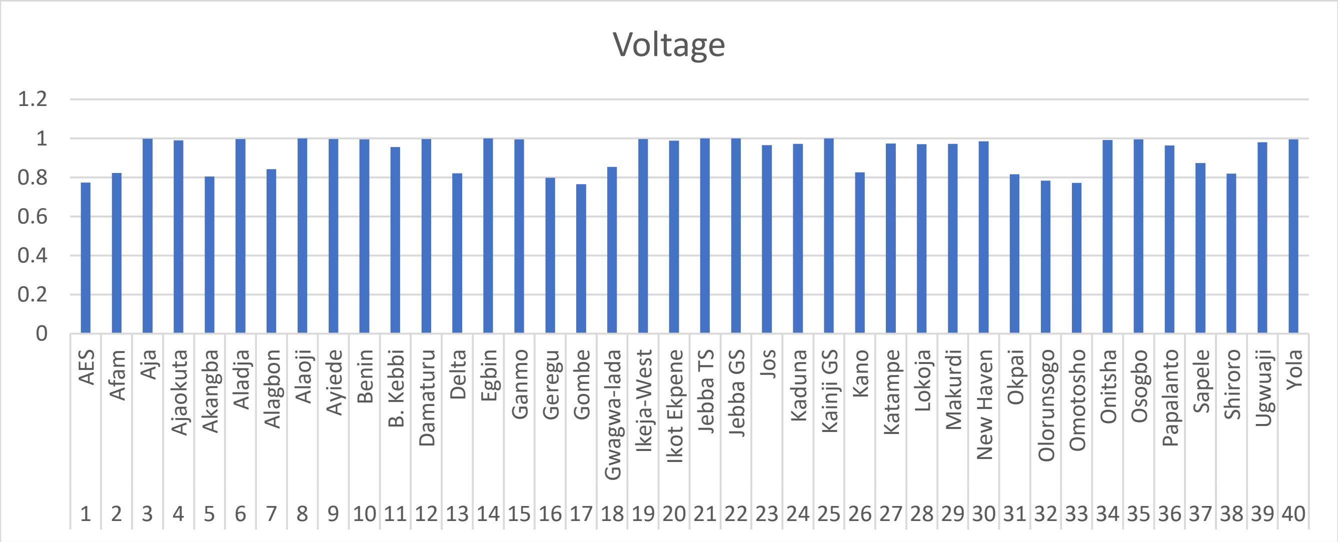

Figure 5: Nigeria 330kV Transmission Line Bus Voltage Profile During Occurrence of a Three Phase Fault on Ajaokuta Bus

DYNAMICS RESPONSE AND VOLTAGE PROFILE OF THE NIGERIA 330KV TRANSMISSION GRID TO OCCURRENCE OF A THREE-PHASE FAULT WITH HVDC INSTALLED IN THE UNSTABLE AJAOKUTA BUS

As aforementioned, the MATLAB/PSAT environment was the tool used for the simulation results are carried out on the. The essence of this is to know the actual effect of the conventional PI controlled HVDC on the transient stability of the system in the existence of a three-phase balanced fault and on the bus voltage violations too. Here, a VSC-HDVC was now installed in complementary or addition to Ajaokuta – Benin transmission line. As before, a three-phase fault was created on Ajaokuta bus (Bus 4) with line Ajaokuta – Benin (4 - 10) removed, by the circuit breakers (CBs) at both ends opening to remove the faulted line from the system. Figures 6 and 7 shows the dynamics responses of the generators for CCT of 350ms.

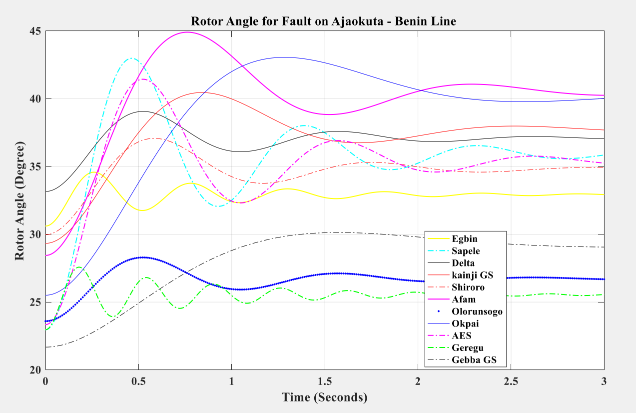

Figure 6: Rotor Angle response for the generators at fault clearing time of 0.35 sec (with only VSC-HVDC)

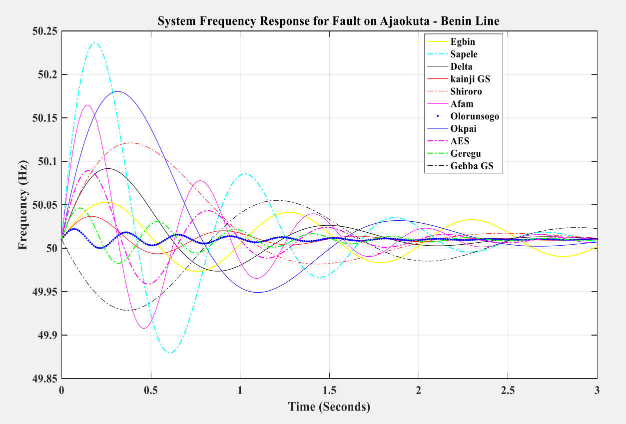

Figure 7: Frequency response for the system generators at fault clearing time of 0.35 sec with only VSC-HVDC

Figures 6 and 7 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 Ajaokuta to Benin transmission line. It can be observed that those generators at Geregu, Sapele, Delta, Okpai and Afam buses which were most critically disturbed and failed to recover after the CCT was cleared at 0.3seconds during a fault occurrence without VSC-HVDC, are now being held stable. This is also attributed to the fact that the VSC-HVDC was able to inject enough power in the two buses (Bus 4 - 10). Hence, with the HVDC in the system the transient stability of the system has been improved as can be seen from the plot of the frequency and the rotor angle of the system generators in Figures 6 and 7 respectively.

The VSC-HVDC was installed between Ajaokuta to Benin bus after the existence of the three phase balanced fault, the voltage profile results of the transmission system are shown in Table 3. This is obtained from the PSAT environment aided power flow analysis of the grid. It can be observed from Table 3 and Figure 8 that the voltage violations at buses 1 (AES), 2 (Afam), 13 (Delta), 16 (Geregu), 31 (Okpai), 32 (Olorunsogbo) and 37 (Sapele) as obtained previously have been corrected. The voltage magnitudes at these buses 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 3: The Simulated Bus Voltage Profile during Occurrence of a Three Phase Fault on Ajaokuta Bus with VSC-HVDC Installed

Bus No	Bus Name	Voltage [p.u.]	Phase Angle [rad]
1	AES	0.905738	0.02336
2	Afam	0.909903	-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	1.000000	-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	0.922923	0.00146
14	Egbin	1.000000	0.007773
15	Ganmo	0.995887	-0.00372
16	Geregu	0.919679	-0.00953
17	Gombe	0.766327	-0.04365
18	Gwagwa-lada	0.853375	-0.03592
19	Ikeja-West	0.996943	0.001354
20	Ikot Ekpene	0.988973	-0.01895
21	Jebba TS	1.000000	0.0004
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	0.941849	-0.05617
32	Olorunsogo	0.919188	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	0.960770	-0.00380
38	Shiroro	0.818990	-0.90286
39	Ugwuaji	0.981078	-0.02538
40	Yola	0.995245	-0.04763

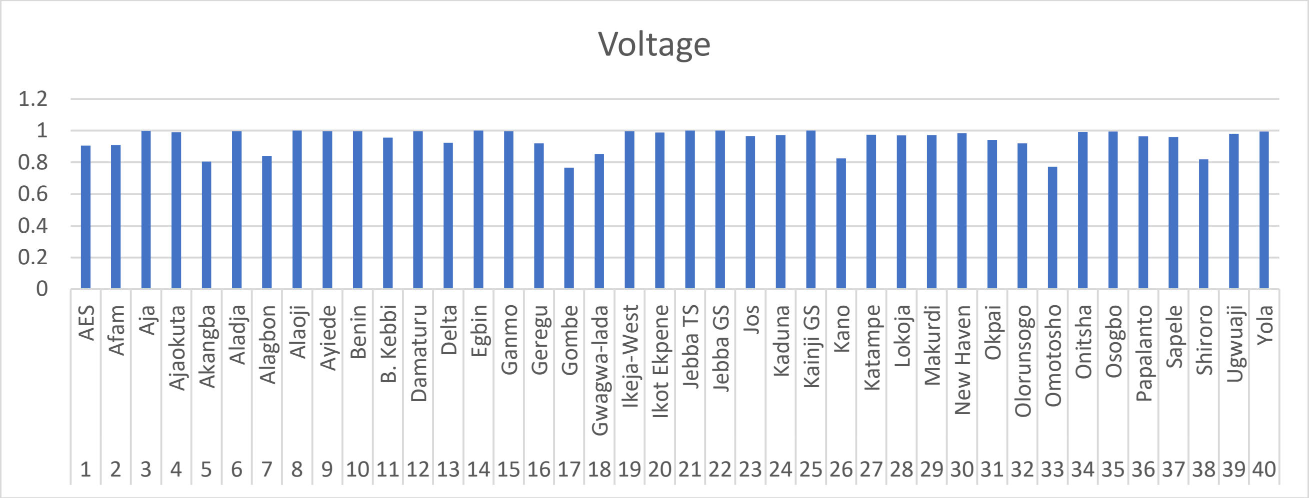

Figure 8: Nigeria 330kV Transmission Line Bus Voltage Profile during Occurrence of a Three Phase Fault on Ajaokuta Bus with VSC HVDC Installed

VI. CONCLUSION AND FUTURE SCOPE

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 the fault location is obtained. The results obtained show that the Nigeria 330-kV transmission network is presently operating on a red alert state which could lead to total blackout if a 3-phase fault occurs on some strategic buses. The result obtained shows that the network losses synchronism when a 3-phase fault of any duration occurs on Ajaokuta bus. Also, Ajaokuta – Benin transmission lines have been identified as critical lines that can excite instability in the power network if removed to clear a 3-phase fault. The result of the eigenvalue analysis shows that numerous buses on the Nigerian 330kV grid apart from the Ajaokuta bus are unstable, this work therefore recommends that researchers should also install/apply PI controlled VSC HVDC links on those remaining unstable buses to compare their impact on the grid.

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REFRENCES

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

[2] Abikhanova G., Ahmetbekova A., Bayat E., Donbaeva A., Burkitbay G. 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, **2018**.

[3] Adepoju G. A., Komolafe, O. A, Aborisade, D.O. 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] Eseosa O. and Odiase F. O. Efficiency Improvement of Nigeria 330kV Network using FACTS devices. International Journal of Advances in Engineering and Technology, **pp. 26- 41, 2012**.

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

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

[7] Hannan, M.A. and K.W. Chan. Transient analysis of FACTS and custom power devices using phasor dynamics. J. Applied Sci., 6: 1074-1081, **2006**. DOI: 10.3923/jas.2006.1074.1081.

[8] Haque M. H. Improvement of First Swing Stability Limit by Utilizing Full Benefit of Shunt FACTS Devices. IEEE Transactions on Power Systems, **Vol.19**, No.4, **pp.1894–1902, 2004.**

[9] Ignatius K. O., Emmanuel A. O. 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)

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