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INTRODUCING ARTIFICIAL NEURAL NETWORK (ANN) TO CONTROL THE VSC-HVDC IN IMPROVING THE TRANSIENT STABILITY OF AJAOKUTA BUS IN THE NIGERIAN 330KV TRANSMISSION SYSTEM

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ABSTRACT

This work presents the application of intelligent Voltage Source Converter – High Voltage Direct Current(VSC-HVDC) for improvement of the transient stability of Nigerian 330kV transmission system. PSAT environment was the tool used to model Nigerian 330kV transmission system. The system load flow was also simulated. The eigenvalue analysis was done on the system buses to obtain the critical buses. In other to establish the current transient stability situation of the network, balanced three-phase fault was introduced in some of these critical buses and lines of the transmission network. This is observed through the dynamic responses of the generators in Nigeria 330-kV grid/network when the fault was introduced. This shows clearly that the Ajaokuta bus and Ajaokuta - Benin Transmission line within the network is critical among others. The load flow analysis confirmed that the system loses synchronism when the fault was applied to the identified critical bus and line. This shows that Nigeria 330-kV transmission system is running presently on a very bad state. Therefore, it urgently requires control measures that will be targeted at of enhancing the transient stability margin of the network to avoid total system shotdown. To this effect, VSC-HVDC was installed along to those critical lines. The inverter and the converter parameters of the HVDC were controlled by the conventional proportional integral (PI) method and artificial neural network. The results obtained showed that 42.86% transient stability improvement on the critical clearing time CCT was achieved when the HVDC was controlled with the ANN when compared to the PI controllers as can be seen by observing the dynamic response of the generators in the Nigeria 330-kV grid/network. Also when compared with the results of other similar works there is about 28.57% transient stability improvement. The result also shows that the system had a faster oscillation/damping when the ANN was applied. 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 as obtained from the power flow analysis in the network in PSAT environment 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.

KEYWORD - Transient Stability, Artificial Neural Network, Transmission line, High Voltage

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INTRODUCTION

Transient stability of the network can also be improved by increasing the system voltage. Increase in the voltage profile of the system implies increase in the power transfer ability. This helps in increasing the difference between initial load angle and critical clearance angle (CCT) hence increase in power allows the machine to rotate through large angle before reaching critical clearance angle. Increase in the X/R ratio in the power system increases the power limit of the line thus helps to improve the stability. High speed circuit breakers assist in clearing the fault as quickly as possible. To maintain the network reliability, there is need to evaluate the response of a power network when subjected to disturbances. When these disturbances occur, the network losses synchronism which can result to total collapse within the network. This necessitated the need for the enhancement of the transient stability in the operation of power system.

RELATED WORK

In their work, Machowski, Kacejko, Nogal & Wancerz, (2013) presented the stabilization of bulky power systems using voltage source-converter-based elevated HVDC links. Different scenarios like the defeat of production, the loss of consumption and changes to the network topology were purposeful in the continental European Network of Transmission System Operators for Electricity (ENTSO-E) system. The simulations showed the presentation increase get with a worldwide MPC-based grid controller; compared to a limited damping controller and HVDC links with constant direction values. Here, the issue is that, the authors have used the model predictive control scheme to control the HVDC links instead of using a ANN to control the HVDC links in the system generators.

MEHODOLOGY

The MATLAB/PSAT software was employed as the tool for the simulations. . PSAT environment was the tool used to model Nigerian 330kV transmission system. and the system load flow was simulated. The critical buses were determined through the eigenvalue analysis of the system buses. The Ajaokuta bus was identified as a critical bus and same with Ajaokuta - Benin transmission line among others. In other to establish the current transient stability situation of the network, balanced three-phase fault was introduced in some of these critical bus and line of the transmission network. The performed load flow analysis shows that the system losses synchronism when the fault was introduced to this identified critical bus and line. The VSC-HVDC was installed along to the Ajaokuta - Benin transmission line. The inverter and the converter parameters of the HVDC were controlled by the conventional proportional integral (PI) method and Artificial Neural Network.

EIGENVALUE ANALYSIS

In a power system, it is required that all modes should be stable. The Eigen value ($\boldsymbol{\gamma}$) gives information about the proximity of the network 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 network to return to stable state in the event of disturbance.

Table 1: 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
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	$-2.0367 \pm$ □8.2287	0.7624	1.1096
14	Egbin	$3.4083 \pm$ □7.1537	0.8320	0.3176
l15	Ganmo	$-0.2562 \pm$ □5.7324	0.8031	0.2113
16	Geregui	$-0.4528 \pm$ □4.2183	0.2803	0.2113
17	Gombe	$-4.6097 \pm$ □7.5635	2.3893	0.3260
18	Gwagwa	$2.3576 \pm$ □8.1273	0.3048	1.0640
19	Ikeja-West	$-0.5284 \pm$ □3.3182	1.1601	0.2639
20	Ikot Ekpene	$4.6097 \pm$ □7.3637	0.5060	0.2680

21	Jebba TS	−1.7356 ± □4.9214	0.0931	4.6422
22	Jebba GS	−1.7653 ± j10.4192	0.1311	0.1422
23	Jos	1.4011 ± j3.1375	0.6534	0.3252
24	Kaduna	−2.1746 ± j6.7011	0.7324	1.9180
25	Kainji GS	−1.9640 ± j5.3208	0.6612	1.2912
26	Kano	2.5376 ± j10.9419	0.3342	1.0768
27	Katampe	−1.7011 ± □3.1375	0.3442	0.0768
28	Lokoja	−2.1746 ± □6.7011	0.2632	0.7139
29	Makurdi	3.0640 ± □5.3208	0.0564	2.6122
30	New Haven	2.0367 ± □8.2287	0.5941	0.6122
31	Okpai	−3.4083 ± □7.5374	0.7456	5.4165
32	Olorunsogo	−0.2562 ± □4.7324	0.2674	3.4165
33	Omotosho	2.7297 ± □5.5635	0.3284	4.2720
34	Onitsha	0.4528 ± □4.2183	0.6259	0.1817
35	Osogbo	−3.8372 ± □6.3756	0.1842	4.3366
36	Papalanto	−2.7653 ± □11.2419	0.4933	0.3021
37	Sapele	1.7301 ± □3.1375	0.2193	3.3021
38	Shiroro	0.1674 ± j4.1170	0.0925	6.3228
39	Ugwuaji	−1.6064 ± j6.8320	0.8232	3.1297
40	Yola	−2.0367 ± j8.2287	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 right side of the S-plane are positive.

POWER FLOW ANALYSIS OF NIGERIA 40 BUS 330KV TRANSMISSION NETWORK FOR TRANSIENT STABILITY IMPROVEMENT DURING OCCURRENCE OF A THREE-PHASE FAULT

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. 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.

Figures 2 shows the PSAT Model of the Nigeria 330kV transmission power system with VSC-HVDC transmission line installed along side with Ajaokuta – Benin, transmission lines respectively. The choice of position for the location of the VSC-HVDC was determined through eigenvalue analysis and also is among the buses that have the lowest damping ratio (as aforementioned). Here, Load flow analysis was performed on the model with bus 4 (Ajaokuta) 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 transient stability improvement.

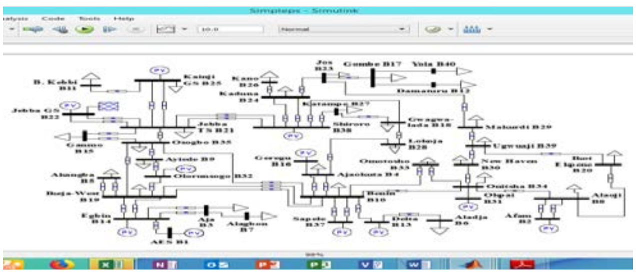

Figure 1: PSAT Model of the Nigeria 330kV transmission power system without VSC-HVDC

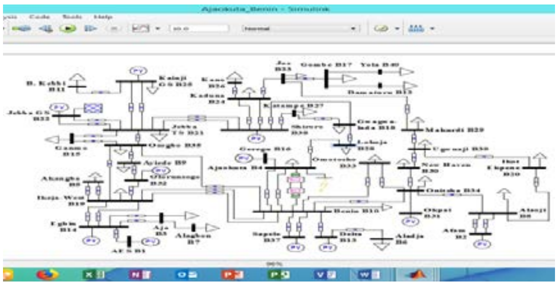

Figure 2: PSAT Model of the Nigeria 330kV transmission power system with VSC-HVDC installed along the Ajaokuta – Benin Transmission Line

RESULTS AND DISCUSSION

RESPONSE OF THE NIGERIA 330KV TRANSMISSION GRID TO OCCURRENCE OF A THREE-PHASE FAULT WITH THE PROPORTIONAL INTEGRAL (PI) CONTROLLED VSC-HVDC WAS INSTALLED IN THE UNSTABLE AJAOKUTA BUS

In this senerio, 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. In this case, 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 3 and 4 show the dynamics responses of the generators for CCT of 350ms.

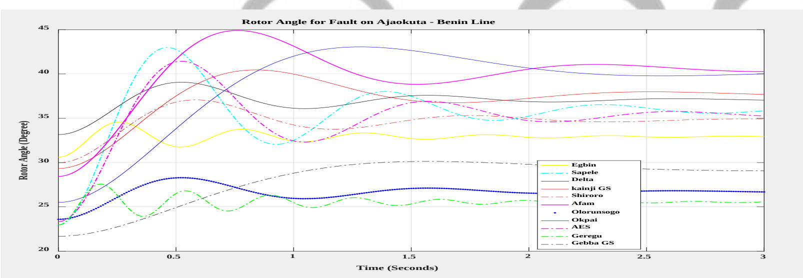

Figure 3: Rotor Angle response of the generators for fault clearing time of 0.35 sec with proportional integral (PI) controlled VSC-HVDC

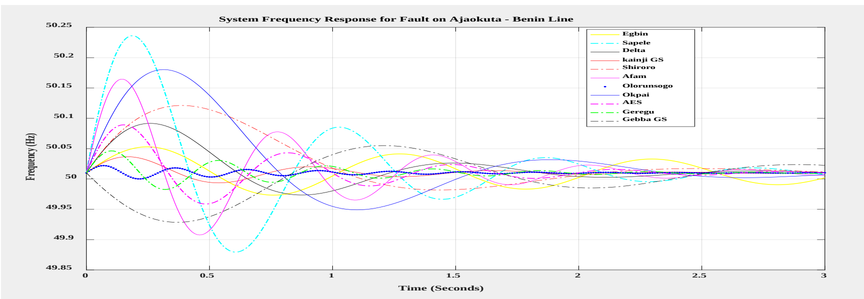

Figure 4: Frequency response of the system generators for fault clearing time of 0.35 sec with proportional integral (PI) controlled VSC-HVDC

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 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 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 3 and 4 respectively.

Table 2: 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

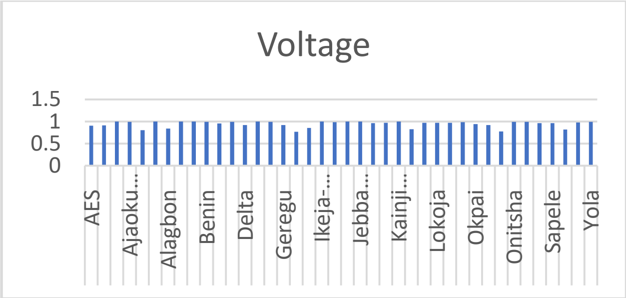

Figure 5: Nigeria 330kV Transmission Line Bus Voltage Profile During Occurrence of a Three Phase Fault on Ajaokuta Bus with VSC-HVDC Installed

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

Here, the position of the ANN controlled VSC-HDVC is at 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 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 500ms.

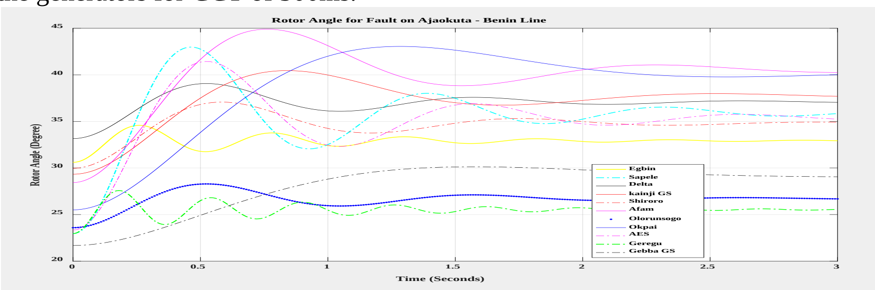

Figure 6: Rotor Angle response of the generators for fault clearing time of 0.5 sec with ANN Controlled VSC-HVDC

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 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 compare to the results obtain when the VSC-HVDC was being controlled by the conventional PI method. This, again 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 and 7, the transient stability of the system has been further improved with the intelligent HVDC in the system.

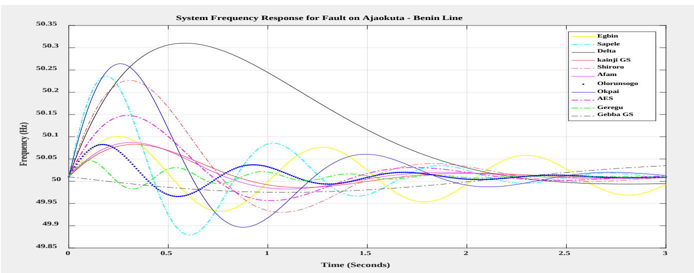

Figure 7: Frequency response of the system generators for fault clearing time of 0.5sec with ANN Controlled VSC-HVDC

The voltage profile results of 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 3 as obtained from the power flow analysis of the network in PSAT environment. It can be observed from Table 2 and Figure 8 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: 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
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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	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	0.997805	-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

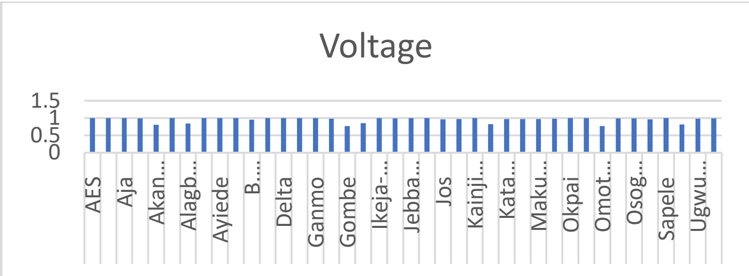

Figure 8: Nigeria 330kV Transmission Line Bus Voltage Profile During Occurrence of a Three Phase Fault on Ajaokuta Bus with ANN Controlled VSC-HVDC Installed

CONCLUSION AND FUTURE SCOPE

In this work, transient stability improvement of Nigeria 330-kV grid system using intelligent VSC-HVDC has been carried out. The location of a balanced 3-phase fault was determined based on the most critical buses within the network which was determined through eigenvalue analysis and damping ratio. The dynamic response for the fault location is obtained. The results obtained shows that the Nigeria 330-kV transmission network is presently operating on a bad 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. 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 many buses on the Nigerian 330kV grid apart from the Ajaokuta bus are unstable. This work therefore recommends that researchers should also apply ANN controlled VSC HVDC links on those remaining unstable buses to compare their impact on the grid.

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AUTHOR'S PROFILE

Okolo C. C graduated from Nnamdi Azikiwe University, Awka Anambra state where he obtained his Bachelors in Engeneering, Masters in Engineering, and is currently doing his PhD in the same institution. He works with the federal ministry of science and technology, Awka Capital Territory, Anambra state, Nigeria. He has published so many research papers in many reputable international journals. He has over 10 years research experience.