ARTIFICIAL NEURAL NETWORK (ANN) CONTROLLED VSC-HVDC AS A MEANS TO ENHANCE THE TRANSIENT STABILITY OF BENIN BUS IN THE NIGERIAN 330KV TRANSMISSION SYSTEM

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ABSTRACT

The intelligent Voltage Source Converter – High Voltage Direct Current (VSC-HVDC) controlled by the artificial neural network for enhancement of transient stability of Nigerian 330kV transmission system is discussed in this paper. The Nigerian 330kV transmission system was modeled in PSAT environment. The load flow of the system was also simulated. Analysis on the eigenvalue and damping ratio of the system buses were determined to identify the critical buses. Then, the balanced three-phase fault was introduced in the critical Benin bus and Ikeja West – Benin Transmission line of the transmission network to establish the existing transient stability situation of the grid by observing the dynamic response of the generator in the network when the fault was applied. This shows that Nigeria 330-kV transmission network is on a critical state. Therefore, an urgent control measure with the aim of enhancing the stability margin of the network to avoid system collapse was required. 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 generalized swing equations for a multi-machine power system are presented. MATLAB/PSAT software was employed as the tool for the simulations. It was obtained that 42.86% critical clearing time (CCT) transient stability improvement was achieved when the HVDC was controlled with the artificial neural network against when compared to the PI controllers as can be seen by observing the dynamic response of the generators in the network. The voltage violations at buses 1, 2, 13, and 37 which were 0.930561,0.905654,0.922923 and 0.920670 as obtained previously when the VSC-HVDC was being controlled by the conventional PI method are now all improved to 1.000000p.u. each.

KEYWORD: Transient, Stability, voltage, Transmission, HVDC, Artificial Neural Network

INTRODUCTION

Nigeria 330-kV transmission network used as the case study in this work 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 enhancement of the transient stability of Nigerian 330kV transmission network using an intelligent controlled VSC-HVDC is presented this paper. The strategy controls the power through the HVDC to assist in making the system more transient stable when there are disturbances. Loss of synchronism is prevented by quickly producing sufficient decelerating energy to counteract accelerating energy gained. It's has been demonstrated that the power flow in the HVDC link is modulated by the adding an auxiliary signal to the current reference of the rectifier firing angle controller to improve the transient stability in power system. The proportional integral derivative (PID) controller works well and damps the first swing oscillation transient so the system remains stable. Therefore, the control of HVDC has the potential for future application to power systems. The PID controllers has been used in the past for controlling HVDC, however Artificial Intelligent technique like ANN promises to be a more intelligent controller that can achieve better result in transient stability improvement of power system

MATERIALS AND METHODS

The PSAT environment was used in the modeling of the existing Nigerian 330kV transmission system and the system load flow was also simulated. MATLAB/PSAT software was employed as the tool for the simulations. The eigenvalue analysis of the system bus was performed to determine the critical buses. The damping ratio was also obtained. Then, the balanced three-phase fault was introduced in the critical Benin bus and Ikeja West – Benin Transmission line of the transmission network to establish the existing transient stability situation of the grid by observing the dynamic response of the generator in the network when the fault was applied. The performed load flow analysis also revealed that the system losses synchronism when the balanced three-phase fault was applied to these identified critical buses and lines. To this effect, VSC-HVDC was installed along the Ikeja West- Benin critical transmission lines. The inverter and the converter parameters of the HVDC were controlled by the conventional proportional integral (PI) method and Artificial Neural Network (ANN).

Eigenvalue Analysis

The investigation of the dynamic behavior of a power system under different characteristic frequencies (‘‘modes’’) is called the Eigenvalue analysis. In a power system, it is necessary for all modes to be stable. Moreover, the target is for all electromechanical oscillations to be damped out as quickly as possible. The Eigen value ($\boldsymbol{\gamma}$) 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 aim here, is determine the generator buses that are most marginally unstable. In order to demonstrate the effect of the HVDC on transient stability the Nigeria 330kV grid, the buses to be subjected to three phase fault should be the buses that are marginally unstable. To do this, the case study network (the existing Nigeria 40 bus 330kV transmission grid) was designed in Matlab/PSAT environment and simulation procedure and results specific to its parameters were obtained. This enabled this work to explore the peculiarity of the Nigerian power system

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	$-2.0367 \pm j8.2287$	0.7624	1.1096
14	Egbin	$3.4083 \pm j7.1537$	0.8320	0.3176
l15	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	Ikot Ekpene	$4.6097 \pm j7.3637$	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	$1.4011 \pm \square 3.1375$	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	$3.0640 \pm \square 5.3208$	0.0564	2.6122
30	New Haven	$2.0367 \pm \square 8.2287$	0.5941	0.6122
31	Okpai	$-3.4083 \pm \square 7.5374$	0.7456	5.4165
32	Olorunsogo	$-0.2562 \pm \square 4.7324$	0.2674	3.4165
33	Omotosho	$2.7297 \pm \square 5.5635$	0.3284	4.2720
34	Onitsha	$0.4528 \pm \square 4.2183$	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 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

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. 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 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 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 enhancement in its transient stability.

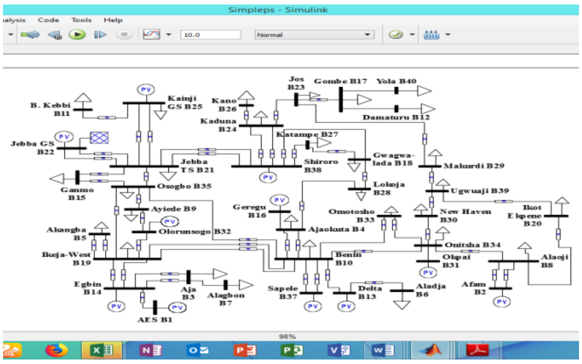

Figure 1: PSAT Model of the Nigeria 330kV transmission power system without VSC-HVDC

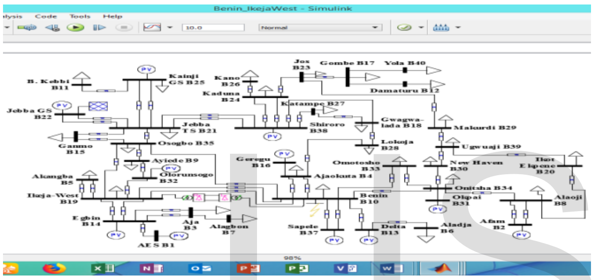

Figure 2: PSAT Model of the Nigeria 330kV transmission power system with VSC-HVDC installed along side with Ikeja West- Benin Transmission Line

RESULTS

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

In this scenario, the 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. 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 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 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 has been improved as can be seen from the plot of the frequency and the power angle of the system generators in Figures 3 and 4 respectively.

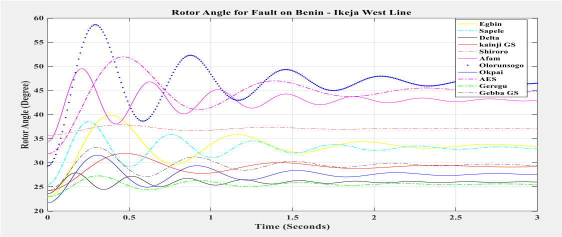

Figure 3: Power Angle response of the generators for fault clearing time of 0.35 sec with proportional integral (PI) controlled VSC-HVDC

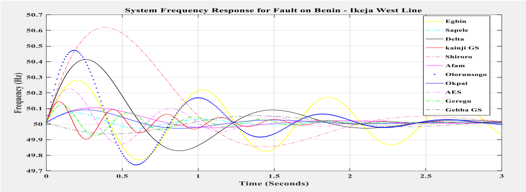

Figure 4: Frequency response of the system generators for fault clearing time of 0.35 sec with proportional integral (PI) controlled VSC-HVDC

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 5 that the voltage magnitudes at the bus voltages are now within the acceptable voltage limit of ±10% for 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

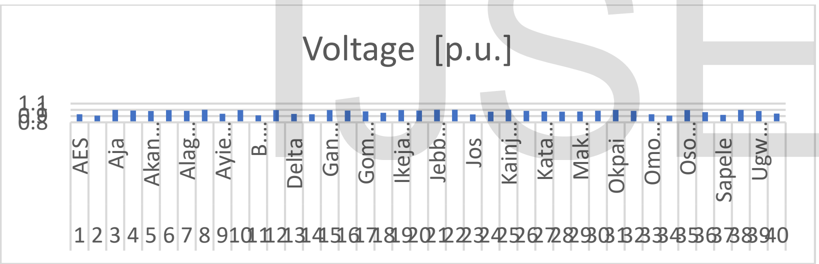

Figure 5: Nigeria 330kV Transmission Line Bus Voltage Profile during Occurrence of a Three Phase Fault on Benin Bus with VSC-HVDC Installed

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

Here, the position of the ANN controlled VSC-HDVC was at Benin – Ikeja West transmission line. As before, a three-phase fault was created on Benin bus (Bus 10) with line Benin – Ikeja west (10 - 19) removed by the CBs at both ends opening to remove the faulted line from the system. Figures 4.25 and 4.26 show the dynamics responses of the generators for CCT of 500ms.

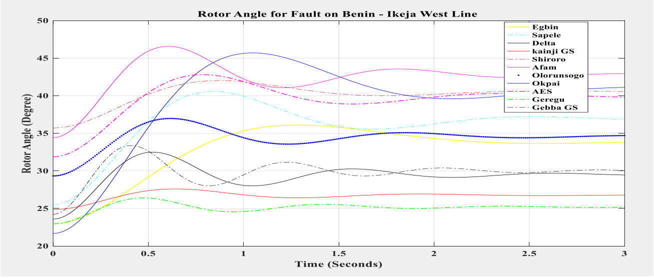

Figure 6: Rotor Angle response of the generators for fault clearing time of 0.5sec with ANN Controlled VSC-HVDC

Figures 6 and 7 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 all the generators in the system which were all critically disturbed during a fault occurrence without VSC-HVDC, 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 10 – 19) in time and most appropriately. Hence, from Figures 4.25 and 4.26, the transient stability of the system has been further improved with the intelligent HVDC in the system.

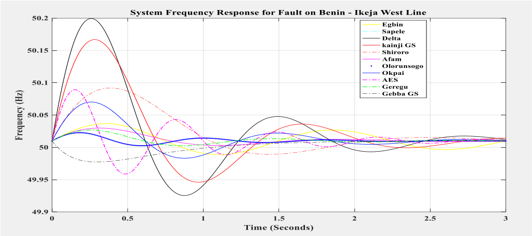

Figure 7: Frequency response of the system generators for fault clearing time of 0.5sec with ANN Controlled VSC-HVDC

The voltage profile results of the Nigerian 40-bus 330kV transmission system with ANN Controlled VSC-HVDC installed between Benin to Ikeja West 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 3 and Figure 7 that the voltage violations at buses 1, 2, 13, and 37 which were 0.930561,0.905654,0.922923 and 0.920670 as obtained previously when the VSC-HVDC was being controlled by the conventional PI method are now all improved to 1.000000p.u. each while the voltages at buses 16, 31, 32 remained the same. 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 Benin Bus with ANN Controlled VSC-HVDC Installed

Bus No	Bus Name	Voltage [p.u.]	Phase Angle [rad]
1	AES	1.000000	0.016368
2	Afam	1.000000	-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
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12	Damaturu	0.996001	0.001354

13	Delta	1.000000	0.000672
14	Egbin	1.000000	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	1.000000	0.00456
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	0.982557	-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	0.997725	-0.72907
34	Onitsha	0.992507	-0.01132
35	Osogbo	0.994828	-0.00446
36	Papalanto	0.963279	-0.04365
37	Sapele	1.000000	-0.00019
38	Shiroro	0.998189	-0.90286
39	Ugwuaji	0.981078	-0.02538
40	Yola	0.995245	-0.04763

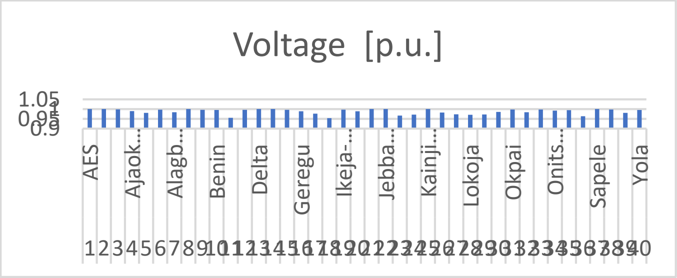

Figure 8: Nigeria 330kV Transmission Line Bus Voltage Profile During Occurrence of a Three Phase Fault on Benin Bus with ANN Controlled VSC-HVDC Installed

DISCUSSION

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 10 – 19) in time and most appropriately. Hence, from Figures 4.25 and 4.26, the transient stability of the system has been further improved with the intelligent HVDC in the system. It can be observed from Table 4.10 and Figure 4.27 that the voltage violations at buses 1, 2, 13, and 37 which were 0.930561,0.905654,0.922923 and 0.920670 as obtained previously when the VSC-HVDC was being controlled by the conventional PI method are now all improved to 1.000000p.u. each while the voltages at buses 16, 31, 32 remained the same. This is as result of the intelligent response of the VSC-HVDC in injecting adequate reactive power timely.

CONCLUSION

In this work, transient stability enhancement of the Nigeria 330-kV grid system using intelligent ANN controlled VSC-HVDC has been carried out. The location of a balanced 3-phase fault was determined based on one of the most critical buses within the network. This was determined through eigenvalue analysis and damping ratio. The dynamic responses were obtained. The results confirms that the Nigeria 330-kV transmission network is presently on a critical 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. The Critical Clearing time and the damping of the system were all improved thereby confirming that the ANN controlled HVD gave a better result than the HVDC which is controlled by th3e conventional PI.

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