CONTROL OF THE VSC-HIGH VOLTAGE DIRECT CURRENT WITH ARTIFICIAL NEURAL NETWORK (ANN) TO IMPROVE THE TRANSIENT STABILITY OF THE NIGERIAN 330KV TRANSMISSION SYSTEM AT MURKUDI BUS/JOS-MARKUDI TRANSMISSION LINE.

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ABSTRACT

This paper presents the application of intelligent Voltage Source Converter – High Voltage Direct Current (VSC-HVDC) for the improvement of the transient stability of Nigerian 330kV transmission system of Markudi bus. PSAT environment was used as a toll to model Nigerian 330kV transmission system The system load flow was also simulated. The critical Markudi bus was determined by performing the eigenvalue analysis of the system buses. Afterwards, a balanced three-phase fault was then Markudi bus/Jos – Markudi Transmission line of the transmission network to obtain the current transient stability situation of the grid by observing the dynamic responses of the generators in the network when the fault was introduced. To this effect, VSC-HVDC was installed along the critical line. The inverter and the converter parameters of the HVDC were controlled by the conventional proportional integral (PI) method and artificial neural network (ANN). 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 artificial neural network when compared with the PI controllers as can be seen by observing the dynamic response of the generators in Nigeria 330-kV grid/network. The result also shows that the system had a faster oscillation/damping when the artificial neural network was applied. The voltage violations at buses 5, 7, 13, 14, 32, 33 and 37 which were 0.905418, 0.889001, 0.958990, 0.979887, 0.971031, 0.907546 and 0.968700 as obtained previously when the VSC-HVDC was being controlled by the conventional PI method are now improved to 0.999541, 0.999541, 1.001000, 0.999887, 0.989031, 0.997546 and 1.000000 respectively. This is as result of the intelligent response of the VSC-HVDC in injecting adequate reactive power timely.

KEYWORD - Artificial Neural Network, Transmission line, HVDC, Transient stability, Proportional Integral, Eigenvalue, Dynamic Responses

INTRODUCTION

Recently, the demand of electricity has 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. 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. Unfortunately, in Nigeria these needs are not met by the 330kV grid due to its instability nature. The improvement of transient stability of Nigeria 330 kV transmission network using HVDC is proposed as the solution to the grid instability. VSC-HVDC limits the impact of faults on the power system. The HVDC links are used within a grid to stabilize it against AC energy flow control problems. When sufficient decelerating energy is quickly produced to counteract accelerating energy gained, loss of synchronism is prevented.

LITERATURE REVIEW

Ignatius and Emmanuel, (2017) maintained that Assessment 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. Their work investigated the dynamic response of the generators in the Nigeria 330-kV grid network when a balanced 3-phase fault was applied with the aim of determining the Critical Clearing Time (CCT) of the transmission network. The simulation was done with the MATLAB software. A real network of Nigeria 330-kV electric grid was also used as a case study in this work. The result that was achieved by this author shows that there are critical buses such as Benin, Onitsha and Jebba Transmission Station (TS) and critical transmission lines such as Benin-Olorunshogo Generating Station (GS) and Jebba TS-Shiroro GS within the network. The results also revealed that there was synchronism loss when a balanced 3-phase fault was applied to these identified critical buses and lines. The results further indicate that Nigeria 330-kV transmission network is on a red-alert, which required urgent control measures with the aim of enhancing the stability margin of the network to avoid system collapse. The good thing here is that the authors have proved that there is the need for the stability improvement for the Nigeria 330kV transmission network through the assessment/determination of the CCT and response of the generators, within the power system, when subjected to a balanced 3-phase fault. Unfortunately, they did not recommend any solution to the above mentioned problem. Hence, this dissertation has proposed the use of an ANN controlled VSC HVDC link.

MEHODOLOGY

MATLAB/PSAT software was used as a 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 and also the damping ratio was used to determine the critical buses. A balanced three-phase fault was injected into the Makurdi bus and Jos - Makurdi Transmission line which was observed as one of the critical bus/transmission line in the transmission network to obtain the existing transient stability situation of the network by observing the dynamic responses of the generators in Nigeria 330-kV network at the time of the introducing the fault. 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. TheVSC-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) and Artificial Neural Network (ANN) method

EIGENVALUE ANALYSIS

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.

Table 1: Extracted output from eigenvalue analysis

Bus Number	Bus Name	Eigen Value (γ)	Damping Ratio (τ)	Participation Factor (%)
1	AES	2.7653 $\pm j8.419$	0.6442	1.0520
2	Afam	-1.9404 $\pm j4.281$	0.4723	0.6197
3	Aja	-2.1746 $\pm j6.701$	0.2632	0.7139
4	Ajaokuta	1.9640 $\pm j3.103$	0.0476	2.6122
5	Akangba	2.0367 $\pm j8.228$	0.5941	0.6122
6	Aladja	-3.4083 $\pm j6.005$	0.7456	2.4165
7	Alagbon	0.2562 $\pm j5.732$	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 ± □7.5635	2.3893	0.3260
18	Gwagwa	2.3576 ± □8.1273	0.3048	1.0640
19	Ikeja-West	-0.5284 ± □3.3182	1.1601	0.2639
20	Ikot Ekpene	4.6097 ± □7.3637	0.5060	0.2680
21	Jebba TS	-1.7356 ± □4.9214	0.0931	4.6422
22	Jebba GS	-1.7653 ± □10.4192	0.1311	0.1422
23	Jos	1.4011 ± □3.1375	0.6534	0.3252
24	Kaduna	-2.1746 ± □6.7011	0.7324	1.9180
25	Kainji GS	-1.9640 ± □5.3208	0.6612	1.2912
26	Kano	2.5376 ± □10.9419	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 ± □4.1170	0.0925	6.3228
39	Ugwuaji	−1.6064 ± □6.8320	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 the 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 BALANCED THREE-PHASE FAULT

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.

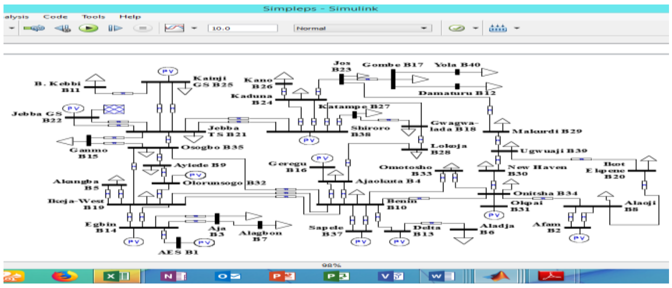

Figure 1: PSAT Model of the Nigeria 330kV transmission power system without VSC-HVDC

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.

Figures 2 shows the PSAT Model of the Nigeria 330kV transmission power system with VSC-HVDC transmission line installed along side with Makurdi – Jos, 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 29 (Makurdi) 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.

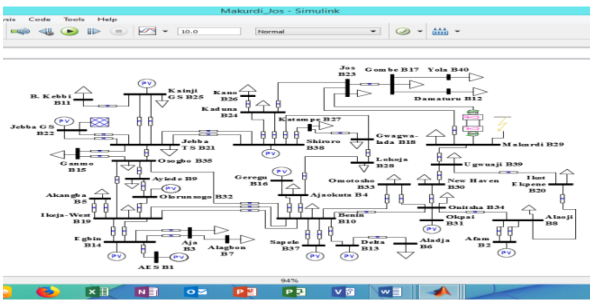

Figure 2: PSAT Model of the Nigeria 330kV transmission power system with VSC-HVDC

installed along side with Makurdi – Jos Transmission Line

RESPONSE OF THE NIGERIA 330KV TRANSMISSION GRID TO OCCURRENCE OF A THREE-PHASE FAULT WITH THE PROPORTIONAL INTEGRAL (PI) CONTROLLED VSC-HVDC INSTALLED IN THE UNSTABLE MAKURDI 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. In this scenario, a VSC-HDVC was now installed in complementary or addition to Makurdi – Jos transmission line. As before, a three-phase fault was created on Makurdi bus (Bus 29) with line Makurdi – Jos (29-23) removed. That is the three-phase fault was cleared 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.

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 Makurdi to Jos transmission line. It can be observed that those four generators at Opkai and Afam buses which were most critically disturbed and failed to recover after the fault was cleared at 0.35 seconds during a fault occurrence without VSC-HVDC, are now being held stable. This is attributed to the fact that the VSC-HVDC was able to inject enough power in the two buses (Bus 29 - 23).

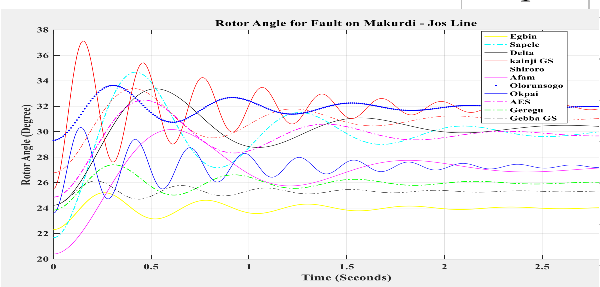

Figure 3: Rotor Angle response of the generators for fault clearing time of 0.35 sec the proportional integral (PI) controlled VSC-HVDC

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 power angle of the system generators in Figures 3 and 4 respectively.

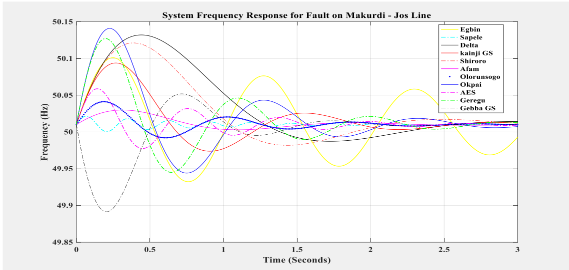

Figure 4: Frequency response of the system generators for fault clearing time of 0.35 sec with proportional integral (PI) controlled VSC-HVDC

The voltage profile results of the Nigerian 40-bus 330kV transmission system with VSC-HVDC installed between Makurdi - Jos bus after the occurrence of the fault are shown in Table 4.5 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 violations at buses 5 (Akangba), 7 (Alagbon), 13 (Delta), 14 (Egbin), 32 (Olorunsogbo), 33 (Omotosho) and 37 (Sapele) as obtained previously have been corrected except for bus 26. 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 2: The Simulated Bus Voltage Profile during Occurrence of a Three Phase Fault on Makurdi Bus with VSC-HVDC Installed

Bus No	Bus Name	Voltage [p.u.]	Phase Angle [rad]
1	AES	1.000000	0.016368
	Afam	1.000000	-0.00533
	Aja	0.998480	0.006284
	Ajaokuta	0.989621	-0.00676
	Akangba	0.905418	-0.10014
	Aladja	0.996952	-0.00231
	Alagbon	0.889001	-0.03763
	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	0.0[illegible]34
13	Delta	0.958990	0.006702
14	Egbin	0.979887	0.071775
15	Ganmo	0.995887	-0.00372
16	Geregu	0.989101	-0.00231
17	Gombe	0.966327	-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.[illegible]0040
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[illegible]
27	Katampe	0.973536	-0[illegible]
28	Lokoja	0.970445	-0[illegible]
29	Makurdi	0.972167	-0[illegible]
30	New Haven	0.985259	-0[illegible]
31	Okpai	0.998001	-0[illegible]
32	Olorunsogo	0.971031	0[illegible]
33	Omotosho	0.907546	-0.72907
34	Onitsha	0.892507	-0.01132
35	Osogbo	0.994828	-0.00446
36	Papalanto	0.963277	-0.04365
37	Sapele	0.968700	-0.00190
38	Shiroro	0.918990	-0.90286
39	Ugwuaji	0.981078	-0.02538
40	Yola	0.995245	-0.04763

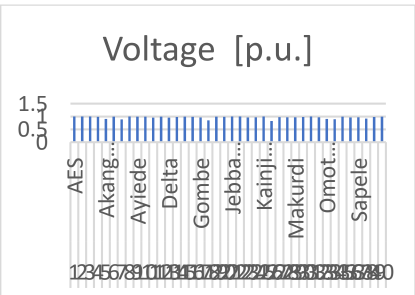

Figure 5: Nigeria 330kV Transmission Line Bus Voltage Profile During Occurrence of a Three Phase Fault on Makurdi Bus with VSC-HVDC Installed

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

In this scenario, a ANN controlled VSC-HDVC was now installed in addition to Makurdi – Jos transmission line. As before, a three-phase fault was created on Makurdi bus (Bus 29) with line Makurdi – Jos (29 - 23) removed. That is the three-phase fault was cleared 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 500ms.

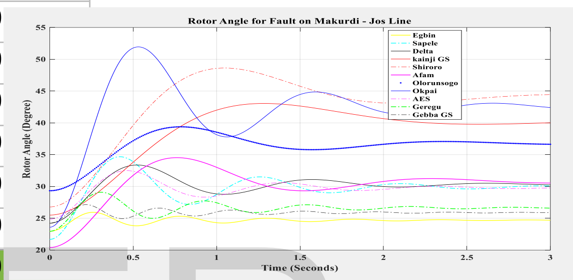

Figure 6: Rotor Angle response of the generators for fault clearing time of 0.5sec with ANN Controlled VSC-HVDC

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 Makurdi to Jos transmission line. It can be observed that the oscillation of the generators at Opkai and Afam buses which were most critically disturbed during a fault occurrence without VSC-HVDC, along with other buses, have achieved faster damping. It can be observed 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 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 29 - 23) in time and most appropriately.

ISSN 2229-5518

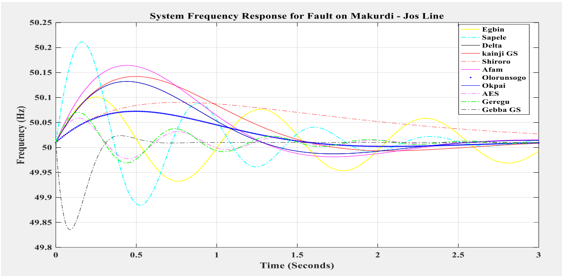

Figure 7: Frequency response of the system generators for fault clearing time of 0.5sec with ANN Controlled VSC-HVDC

Interestingly, it can be observed that a quick recharging of the DC-link capacitor due to a power injection created an additional damping of the post fault oscillations of the AC-side power angle and frequency oscillations, hence enhancing transient stability. Therefore, it could be said that from Figures 6 and 7, the transient stability of the system has been further improved with the intelligent HVDC in the system. The voltage profile results of the Nigerian 40-bus 330kV transmission system with ANN Controlled VSC-HVDC installed between Makurdi to Jos bus after the occurrence of the fault are shown in Table 4.8 as obtained from the power flow analysis of the network in PSAT environment. It can be observed from Table 3 and Figure 8 that the voltage violations at buses 5, 7, 13, 14, 32, 33 and 37 which were 0.905418, 0.889001, 0.958990, 0.979887, 0.971031, 0.907546 and 0.968700 as obtained previously when the VSC-HVDC was being controlled by the conventional PI method are now improved to 0.999541, 0.999541, 1.001000, 0.999887, 0.989031, 0.997546 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 Makurdi Bus with ANN Controlled VSC-HVDC Installed

Bus No	Bus Name	Voltage [p.u.]	Phase [rad]
1	AES	1.000000	
2	Afam	1.000000	
3	Aja	0.998480	
4	Ajaokuta	0.989621	
5	Akangba	0.999541	
6	Aladja	0.996952	
7	Alagbon	0.889001	-0.03763
	Alaoji	1.000000	-0.00962
	Ayiede	0.996654	0.001761
	Benin	0.995594	-0.00382
	B. Kebbi	0.955445	-0.04433
	Damaturu	0.996001	0.001354
13	Delta	1.001000	0.006702
14	Egbin	0.999887	0.071775
15	Ganmo	0.995887	-0.00372
16	Geregu	0.989101	-0.00231
17	Gombe	0.966327	-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	0.00040
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	0.998001	-0.03763
32	Olorunsogo	0.989031	0.04615
33	Omotosho	0.997546	-0.72907
34	Onitsha	0.892507	-0.01132
35	Osogbo	0.994828	-0.00446
36	Papalanto	0.963277	-0.04365
37	Sapele	1.000000	-0.00190
38	Shiroro	0.918990	-0.90286
39	Ugwuaji	0.981078	-0.02538
40	Yola	0.995245	-0.04763

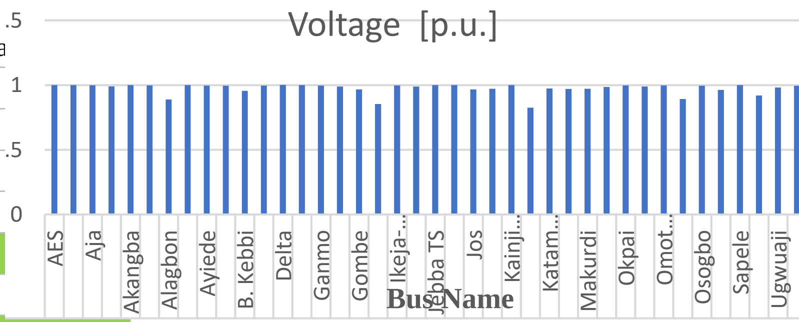

Figure 8: Nigeria 330kV Transmission Line Bus Voltage Profile During Occurrence of a Three Phase Fault on Makurdi Bus with ANN Controlled VSC-HVDC Installed

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 was determined based on the most critical bus within the network which was determined from their eigenvalue and damping ratio. The dynamic response of the fault at each stage of the work was obtained. The results obtained shows 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. It was obtained that when a 3-phase fault of any duration occurs on Makurdi bus, the system losses synchronism immediately. Also, Jos - Makurdi 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 Markudi 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.

ACKNOWLEDGMENT

All praises, thanks and sincere gratitude and appreciation are to God Almighty, the Lord of the world, for helping us to accomplish this work.

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