Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2020, 7(2):156-164**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Improving Transient Stability of the Nigerian 330kV Transmission System using ANN based VSC High Voltage Direct Current Method on Jos - Markudi Transmission Line

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Abstract Improvement of the response of generators, within a power system, when it been subjected to disturbances, has been a serious challenge to power system engineers and researchers. 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. First, the current transient stability condition 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 injected 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 indicates that there are critical buses suchas Makurdi and critical transmission lines such as Jos - Makurdi Transmission line within the network. The results also show that when a balanced three-phase fault was applied to these identified critical buses and lines, the system losses synchronism. The results further indicated that the Nigeria 330-kV transmission network is presently on red-alert, which requires urgent control measures with the aim of enhancing the stability margin of the network to avoid the system from collapsing. To address this problem, 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 enhancement was achieved when the HVDC was controlled with the artificial neural.

Keywords buses, high voltage, stability, transmission, transient

1. 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 [1-4]. 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.

2. Materials and Methods

2.1. Artificial Neural Network (ANN)

The ANNs are very different from expert systems since they do not need a knowledge base to work. Instead, they have to be trained with numerous actual cases. An ANN is a set of elementary neurons which are connected together in different architectures organized in layers of what is biologically inspired. An elementary neuron can be seen like a processor which makes a simple non-linear operation of its inputs producing its single output. The ANN techniques are attractive because they do not require tedious knowledge acquisition, representation and writing stages and, therefore, can be successfully applied for tasks not fully described in advance. The ANNs are not programmed or supported by knowledge base as are Expert systems. Instead, they learn a response based on a given inputs and required output by adjusting the node weights and biases accordingly. The speed of processing, allowing real time applications, is also advantage.

Since ANNs can provide excellent pattern recognition, they are proposed by many researchers to perform different tasks in power system relaying for signal processing and decision making [5].

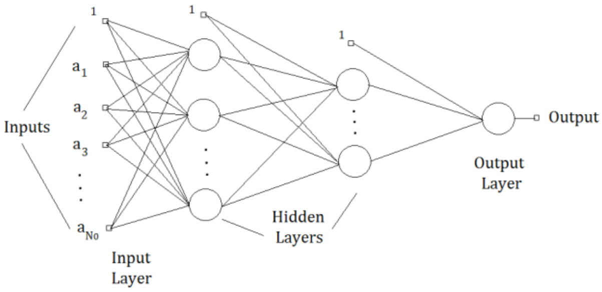

Figure 1: A basic three-layer architecture of a feed-forward ANN

2.2. 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

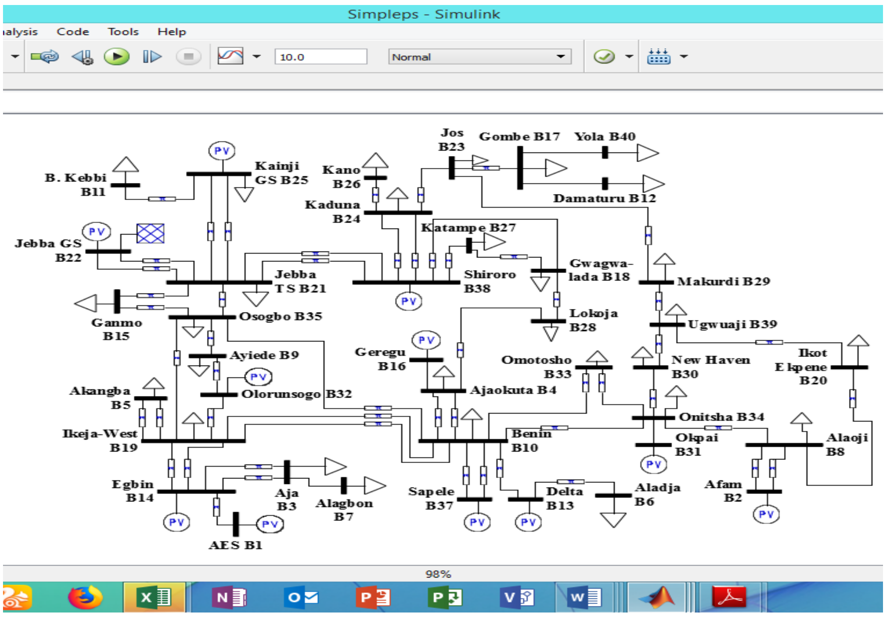

Figure 2: PSAT Model of the Nigeria 330kV transmission power system without VSC-HVDC

2.3. 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: 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	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. Results and Discussion

3.1. Response of the Nigeria 330kV Transmission Grid to Occurrence of a Three-Phase Fault without ANN Controlled VSC-HVDC Installed in the Unstable Buses Fault on the Markudi Transmission line

In this scenario, 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 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 Makurdi to Benin transmission line. It can be observed that generators at Opkai and Afam buses were most critically disturbed and failed to recover after it was cleared at 0.35seconds. These two generators in the system lost synchronism and became unstable as shown in Figures 3 and 4.

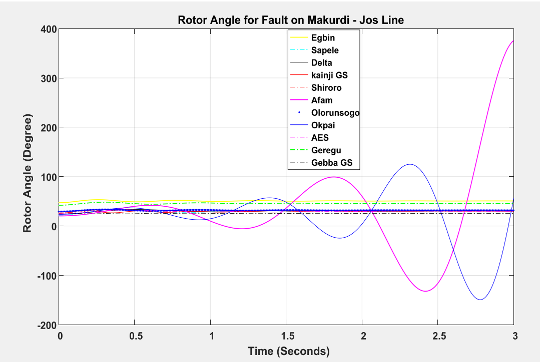

Figure 3: Rotor Angle response of the generators for fault clearing time of 0.35sec without any VSC-HVDC

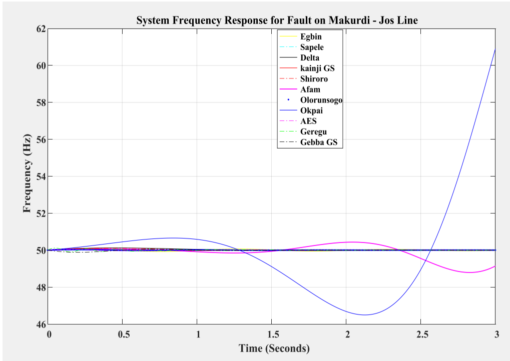

Figure 4: Frequency response of the system generators for fault clearing time of 0.35 sec without any VSC-HVDC

The effect on the bus voltage magnitude for the three phase fault on Bus 29 was also examined. The voltage profile results of the Nigerian 40-bus 330kV transmission system 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 that there are serious voltage violations at buses 5 (Akangba), 7 (Alagbon), 13 (Delta), 14 (Egbin), 26 (Kano), 32 (Olorunsogbo), 33 (Omotosho) 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: The Simulated Bus Voltage Profile during Occurrence of the Three Phase Fault

Bus No	Bus Name	Voltage [p.u.]	Phase Angle[rad]
1	AES	1.000000	0.016368
2	Afam	1.000000	-0.00533
3	Aja	0.980480	0.006284
4	Ajaokuta	0.974396	-0.00676
5	Akangba	0.800057	-0.10014
6	Aladja	0.990952	-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	0.800500	-0.200672
14	Egbin	0.704520	-0.083373

15	Ganmo	0.995887	0.00372
16	Geregu	0.989101	-0.00231
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	0.00781
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	0.778346	-0.47321
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	0.704592	-0.53658
38	Shiroro	0.818990	-0.90286
39	Ugwuaji	0.981078	0.02538
40	Yola	0.995245	-0.04763

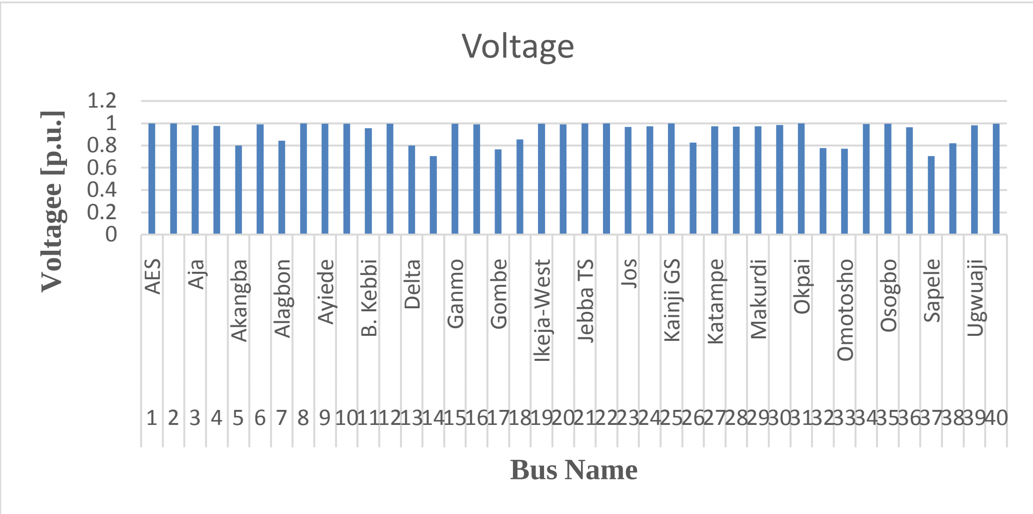

Figure 5: Nigeria 330kV Transmission Line Bus Voltage Profile during Occurrence of a Three Phase Fault on Makurdi Bus

3.2. Installation of the VSC-HVDC to the Nigeria 40 Bus 330kv Transmission Network to obtain Transient Stability Improvement during Occurrence of a Three-Phase Fault on the Markudi Transmission line

PSAT Model of the Nigeria 330kV transmission power system with VSC-HVDC installed along side with Makurdi – Jos Transmission Line is shown in Figures 6 below. The choice of location of the VSC-HVDC was obtained through eigenvalue analysis. The demonstration for the transient stability improvement on the Nigeria 330-kV grid network, in this work, considered Markudi - Jos Transmission Line.

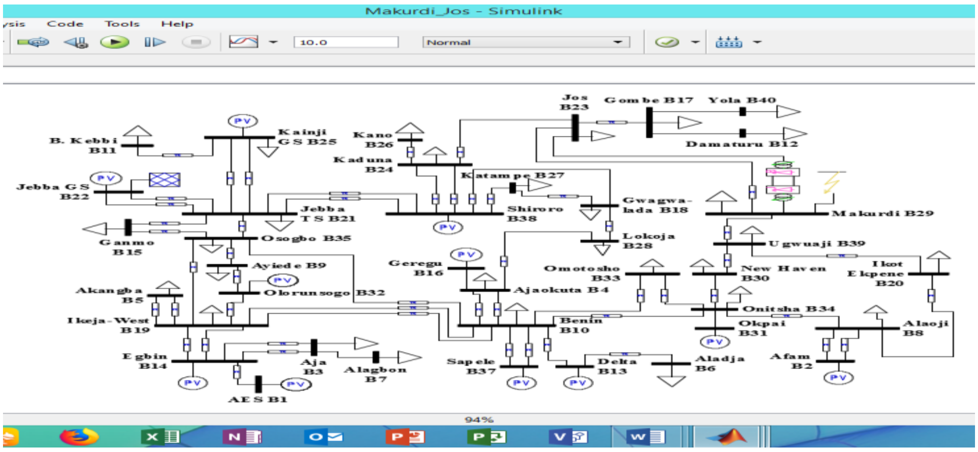

Figure 6: PSAT Model of the Nigeria 330kV transmission power system with VSC-HVDC installed along side with Markudi – Jos West Transmission Line

3.3. Response of the Nigeria 330kV Transmission Grid to Occurrence of a Three-Phase Fault with ANN Controlled VSC-HVDC Installed in the Unstable Buses

The artificial neural network (ANN) was used to control and regulate the parameters of the inverter and rectifier 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 CCT for the phase fault has been improved from 350ms to 500ms resulting to a 42.86% increment. 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. It is observed that the dynamics responses of the generators for CCT is 500ms. Figures 6.0 and 7.0 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 the 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. 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. 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 7 and 8, the transient stability of the system has been further improved with the intelligent system.

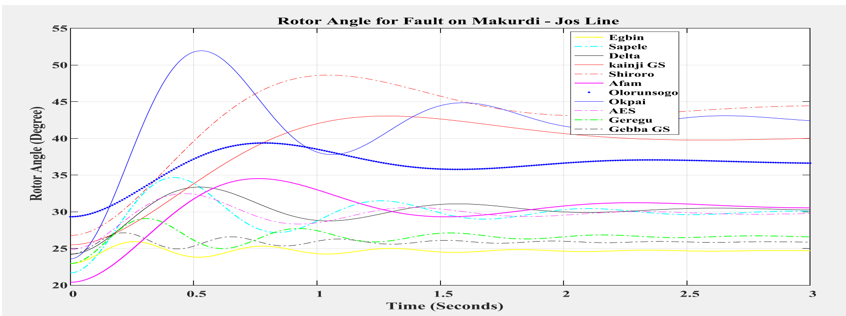

Figure 7: Rotor Angle response of the generators for fault clearing time of 0.5sec with ANN Controlled VSC-HVDC

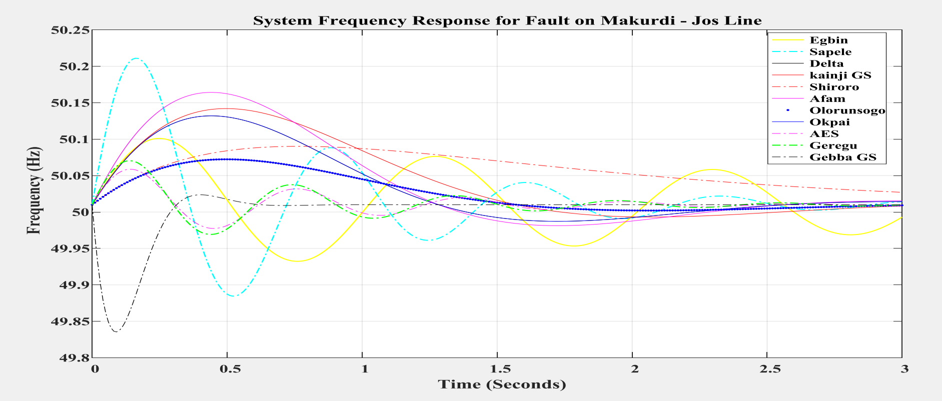

Figure 8: Frequency response of the system generators for fault clearing time of 0.5sec with ANN Controlled VSC-HVDC

The voltage profile results of the Nigerian 40-bus 330kV transmission system with ANN Controlled VSC-HVDC installed between Makurdi to Jos 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 9 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 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	0.999541	-0.10014
6	Aladja	0.996952	-0.00231
7	Alagbon	0.889001	-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	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	IkotEkpene	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

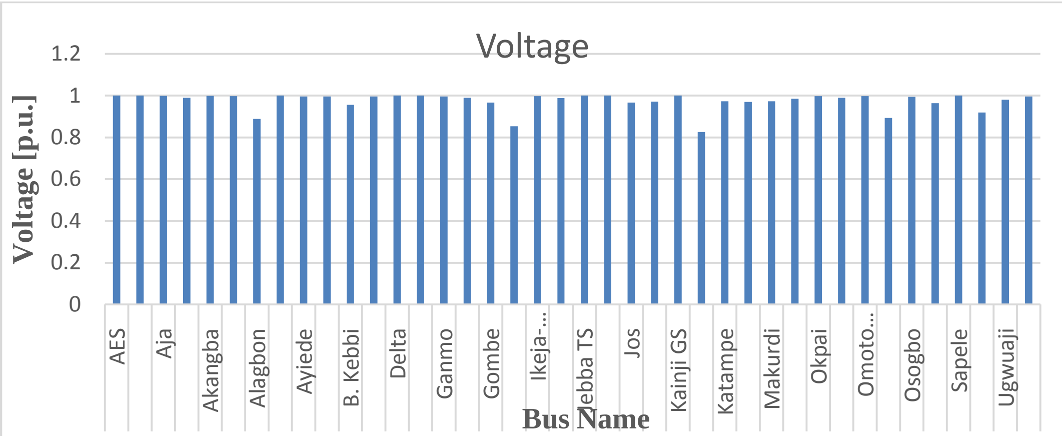

Figure 9: Nigeria 330kV Transmission Line Bus Voltage Profile during Occurrence of a Three Phase Fault on Makurdi Bus with ANN Controlled VSC-HVDC Installed

4. Conclusion

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. The dynamic responses for various fault locations are 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. The result obtained shows that when a 3-phase fault of any duration occurs on Makurdi, Ajaokuta or Benin bus, the system losses synchronism immediately. Also, Jos - Makurdi and Ikeja West - Benin and 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.

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