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Introduction of Artificial Neural Network Controlled VSC-HVDC for Transient Stability Improvement of Ajaokuta Bus/Ajaokuta-Benin Transmission Line Using Eigen value Analysis

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ABSTRACT

This work presents the introduction of Artificial Neural Network controlled Voltage Source Converter HVDC for enhancement of the transient stability of the Nigerian 330kV transmission system. This shows the improvement of the dynamic response of generators, within a power system, when subjected to various disturbances. This has been a serious problem to power system researchers for a very long time. The system was modeled in Power System Analysis Toolbox (PSAT) environment and MATLAB software was employed as the tool for the simulations. To obtain the critical buses, the eigenvalue analysis of the system was performed. To establish the existing transient stability situation of the network, a three-phase balanced fault was applied to some of these critical buses and lines of the transmission network and the dynamic responses was observed fault was applied. This confirmed Ajaokuta bus and transmission line critical, which include Ajaokuta - Benin within the network. VSC-HVDC was installed along to these critical buses and lines. The Artificial Neural Network was used to control the inverter/converter parsmeters. It was observed that there was 33.33% improvement with the critical clearing time CCT. This was confrirmed when the HVDC was controlled intelligently unlike that of the conventional proportional integral method. The voltage profile result and the damping were improved when the ANN was installed.

KEYWORDS: Transmission Line, Eigenvalue Analysis, Transient Stability, Artificial Neural Network, VSC-HVDC

INTRODUCTION

In recent times, the demand for electricity has radically increased and a modern power system becomes a difficult network of transmission lines. Transient stability which can be defined as the ability of the power system to maintain certain parameters within limit of occurrence of the transient on power system like sudden load discharge, grid failure or any kind of fault can also be seen as the ability of a power system to regain its normal operating condition after sudden and severe disturbance in system. Those disturbances may be because of the application of faults, clearing of faults, switching on and off surges in EHV system.

METHODOLOGY

PSAT environment and MATLAB/PSAT software were employed to model the existing Nigerian 330kV transmission system. Afterwards, the system load flow was performed. In other to obtain the critical buses in the case network, the eigenvalue analysis of the system was performed. The damping ratio (τ) is an indication of the ability of the system to return to stable state in the event of disturbance. For eigenvalue determination of stability, all the values must have negative real part and will lie on the left side of the S-plane. However, if any of the established eigenvalue lies on the positive right side of the S-plane, thus indicates oscillation in the system hence unstable.

The aim here is to determine the generator buses that are most marginally unstable. A balanced three-phase fault was introduced in the network to determine the transient stability condition of the network. This was achieved by the observing the dynamic responses of the generators in the network after the existence of a fault. This shows clearly that there exist three most critical buses which are Ajaokuta and critical transmission line, Ajaokuta - Benin within the network. From the observed analysis, it was confirmed that the network losses synchronism when the three-phase balanced fault was applied to these identified critical bus and line. The VSC-HVDC was installed along the critical lines. The Artificial Neural Network was used to control the inverter and converter parameters of the HVDC. The generalized swing equation for a multi-machine power system was also used. The flowchart is shown in Figure 1.0.

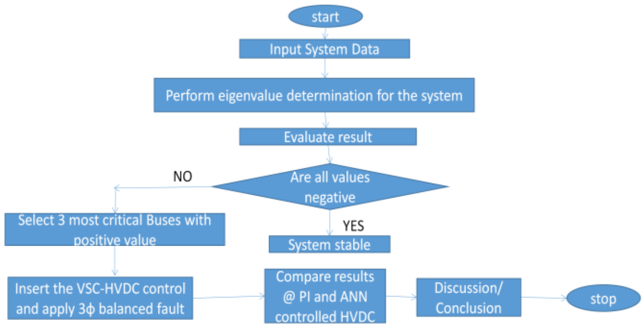

Figure 1.0: Flowchart for determination of Transient stability using Eigenvalue method

Controller for the VSC-HVDC Transmissions

The Model of HVDC Controller is shown in Figure 3.1. The ANN controller is connected in parallel with PI controller as shown in Figure 3.1.

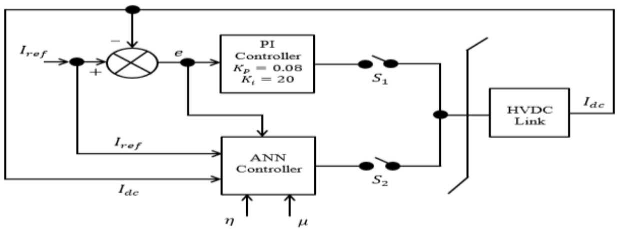

Figure 2.0: A schematic diagram of an HVDC system generic controller

Table 1.0: Training data-set for the Artificial Neural Network controller

I_{ref}	I_{dc}		
	Makurdi – Jos	Ajaokuta – Benin	Ikeja-West –Benin
5.205	4.959	5.887	5.766
5.370	5.989	5.101	5.853
5.120	5.766	5.327	5.996
5.830	5.853	5.375	5.988
5.470	4.996	5.943	5.097
5.650	5.988	4.973	5.943
5.330	5.007	5.042	5.423
5.804	5.020	5.200	4.971
5.210	5.966	5.434	5.053
5.190	5.971	5.423	5.825
5.130	5.030	5.091	5.973
5.350	5.182	5.577	5.976
5.970	5.973	5.036	5.972
5.460	5.970	5.445	5.985
5.560	5.972	5.167	5.327
5.302	4.985	5.259	5.375
5.010	5.076	5.332	5.799
5.480	5.385	4.837	5.198
5.660	5.498	5.197	5.094
5.930	5.100	5.104	5.242
5.110	5.003	5.009	5.697
5.030	5.918	5.057	5.297
5.625	5.090	5.188	5.176
5.340	5.198	5.210	5.385
5.910	5.276	5.032	5.699
5.080	5.285	5.737	5.698
5.290	5.197	5.360	5.930
5.940	5.297	5.452	5.850

5.350	5.797	5.678	5.027
5.801	5.398	4.795	5.350
5.101	5.8087	5.324	5.179
5.640	5.438	5.370	5.919
5.560	5.549	5.470	5.090

Table 1.0 shows the neural network controller training data set. The entire input data set (shown in Table 1.0) were subdivided into three; 60%, 20%, 20% for the training set, validation set and testing set respectively giving a set of three inputs and one output in each input-output pair. The output of the neural network is the firing angle. Hence, each input output pair consists of two inputs and one output.

The inputs to the ANN controller are I_{ref} and I_{dc} and its output is the firings angle$\propto$. The speed of the controller and the system stability will depend on the learning rate η and the momentum term μ used in adjusting the weights of the ANN. The ANN controller is trained on-line according to the I_{ref} and I_{dc} and by using back-propagation algorithm. The ANN learns by adjusting the weights V_n and B_n in the hidden layer and the weights W_n and B_n in the output layer.

The overall network/load representation comprises a large sparse nodal admittance matrix equation with a structure similar to that of the power-flow problem. The network equation is written in matrix form as:

$$\bar{I}_L = Y_N \bar{V} \qquad 1.1$$

Where $\bar{V}$ is the node voltage and $\bar{I}$ is the node current. The node admittance matrix Y_N is symmetrical, except for dissymmetry introduced by phase-shifting transformers.

This can be represented in steady state-space form as follows:

$$\boldsymbol{A}x = \hat{x} \qquad 1.2$$

To obtain the solution of equation (1.2), a scalar parameter λ called the eigenvalue is introduced such that equation (1.2) becomes;

$$\boldsymbol{A}x = \lambda x \qquad 1.3$$

Where $\boldsymbol{A} = [\boldsymbol{a}_{i1}]_{an}$ n x n square matrix, where x is n x 1 vector and λ is a number (scalar) parameter. Clearly the solution $x = 0$ for λ is usually not useful and thus is neglected.

For non-trivial solutions i.e.$x \neq 0$, the values of λ are called the eigenvalues and the characteristics values or latent roots of the matrix A and the corresponding solutions of equation (1.3) are called eigenvectors or characteristic vectors of A. Expressed as separate equations we have;

$$\boldsymbol{A}.\, x - \lambda x = 0 \qquad 1.4$$

$$(\boldsymbol{A} - \lambda \boldsymbol{I})x = 0 \qquad 1.5$$

Notice that the unit matrix $\boldsymbol{I}$was introduced so that λ can be subtracted from matrix A. Now for equation (1.5) to have a non-trial solution, determinant of $|\boldsymbol{A} - \lambda \boldsymbol{I}|$ must be equal to zero. Hence

$$|\boldsymbol{A} - \lambda \boldsymbol{I}| = \begin{bmatrix} a_{11} - \lambda & a_{12} & \cdots & a_{1i} \\ a_{21} & a_{22} - \lambda & \cdots & a_{2i} \\ \vdots & \vdots & & \vdots \\ a_{i1} & a_{i2} & \cdots & a_{ii} - \lambda \end{bmatrix} = 0 \qquad 1.6$$

Expansion of equation (1.6) gives the characteristics equation. The n solutions of $\lambda = \lambda 1$, $\lambda 2$, $\lambda 3$ … . λn are eigenvalues of A.

The output from the eigenvalue analysis on the PSAT model of the Nigeria 330kV transmission grid is extracted and tabulated in Table 2.0 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 2.0 Extracted output from eigenvalue analysis

Bus Number	Bus Name	Eigen Value (γ)	Damping Ratio (ξ)	Participation Factor (%)
1	AES	2.7653 ± j8.4192	0.6442	1.0520
2	Afam	−1.9404 ± j4.2813	0.4723	0.6197
3	Aja	−2.1746 ± j6.7011	0.2632	0.7139
4	Ajaokuta	1.9640 ± j3.1032	0.0476	2.6122
5	Akangba	2.0367 ± j8.2287	0.5941	0.6122
6	Aladja	−3.4083 ± j6.0053	0.7456	2.4165
7	Alagbon	0.2562 ± j5.7324	0.6745	0.4165
8	Alaoji	−0.4528 ± j4.2183	0.6259	1.0817
9	Ayiede	−2.7653 ± j11.2419	0.4933	0.3021
10	Benin	2.8730 ± j6.1437	0.0219	3.3021
11	Brenin Kebbi	−2.1674 ± j5.1101	1.3511	0.3228
12	Damaturu	1.6064 ± j6.8320	0.8232	3.1297
13	Delta	−2.0367 ± j8.2287	0.7624	1.1096
14	Egbin	3.4083 ± j7.1537	0.8320	0.3176
15	Ganmo	−0.2562 ± j5.7324	0.8031	0.2113
16	Geregui	−0.4528 ± j4.2183	0.2803	0.2113
17	Gombe	−4.6097 ± j7.5635	2.3893	0.3260
18	Gwagwa	2.3576 ± j8.1273	0.3048	1.0640
19	Ikeja-West	−0.5284 ± j3.3182	1.1601	0.2639
20	Ikot Ekpene	4.6097 ± j7.3637	0.5060	0.2680
21	Jebba TS	−1.7356 ± j4.9214	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 ± j3.1375	0.3442	0.0768
28	Lokoja	−2.1746 ± j6.7011	0.2632	0.7139
29	Makurdi	3.0640 ± j5.3208	0.0564	2.6122
30	New Haven	2.0367 ± j8.2287	0.5941	0.6122
31	Okpai	−3.4083 ± j7.5374	0.7456	5.4165
32	Olorunsogo	−0.2562 ± j4.7324	0.2674	3.4165
33	Omotosho	2.7297 ± j5.5635	0.3284	4.2720
34	Onitsha	0.4528 ± j4.2183	0.6259	0.1817
35	Osogbo	−3.8372 ± j6.3756	0.1842	4.3366
36	Papalanto	−2.7653 ± j11.2419	0.4933	0.3021
37	Sapele	1.7301 ± j3.1375	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

Looking at the above tabulation, it's a clear fact that the Nigeria 330kV transmission grid network is not stable. As we can see, all the eigenvalues are not on the left side (negative) of the S-plane and this confirms the reason why the network is unstable.

The Nigerian 40 Bus 330kv Transmission Network during the Occurrence of a Three-Phase Fault for Transient Stability Improvement when VSC-HVDC was installed.

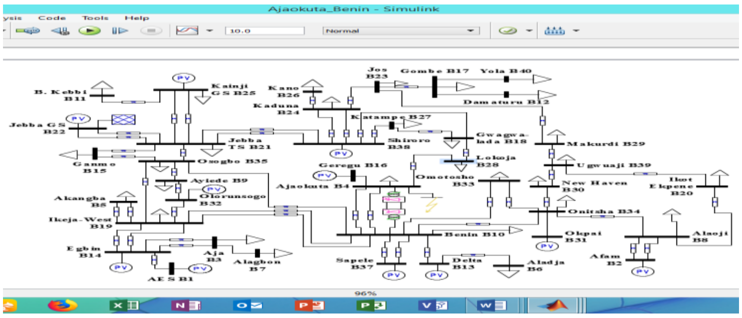

Figure 3.0: PSAT Model of the network when the VSC-HVDC is installed along Ajaokuta – Benin Transmission Line

Figures 3.0 shows the PSAT Model of the network when the VSC-HVDC is installed along Ajaokuta – Benin Transmission Line, transmission lines respectively. The buses that have the lowest damping ratio (as aforementioned) was considered the most marginally affected buses.

Response of the Nigeria 40 Bus 330kV Transmission Network towards the occurrence of a 3-Phase Fault at Ajaokuta Bus

The results obtained from the simulation are presented in this section. The simulation results are carried out on the MATLAB/PSAT environment. The demonstration for the transient stability analysis on the Nigeria 330-kV grid network in this work, considered the Ajaokuta Bus. A three phase fault was created on the transmission lines connected to it (very close to the buses)

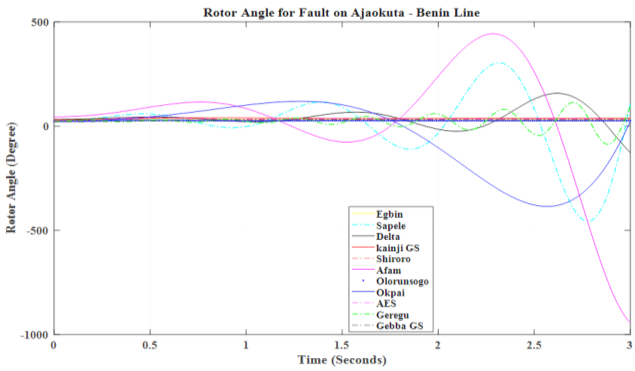

Fig 4.0: Rotor Angle response of the generators for fault clearing time of 0.35sec (without any VSC-HVDC)

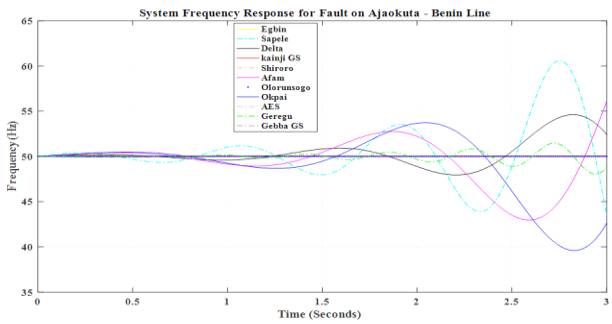

Fig 5.0: Frequency response of the system generators for fault clearing time of 0.35sec (without any VSC-HVDC)

In this scenario, 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 0.3seconds. These five generators in the system lost synchronism and became unstable as shown in Figures 4.0 and 5.0.

Table 3.0: 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

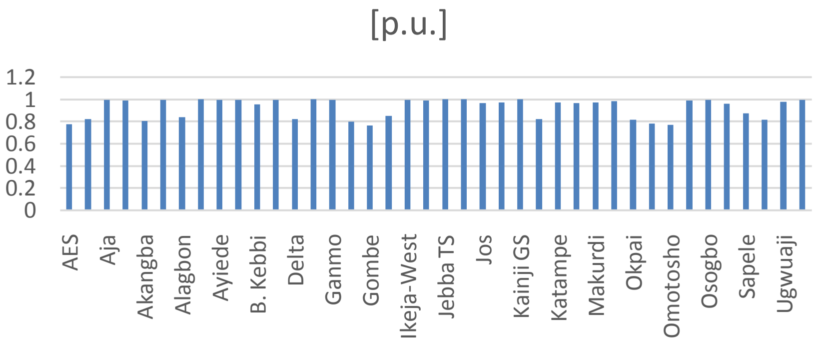

Figure 6.0: Nigeria 330kV Transmission Line Bus Voltage Profile During Occurrence of a Three Phase Fault on Ajaokuta Bus

It can be observed from Table 3.0 that there are serious voltage violations at buses 1 (AES), 2 (Afam), 13 (Delta), 16 (Geregu), 31 (Okpai), 32 (Olorunsogbo) and 37 (Sapele).

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

Three Phase Fault at Ajaokuta Bus

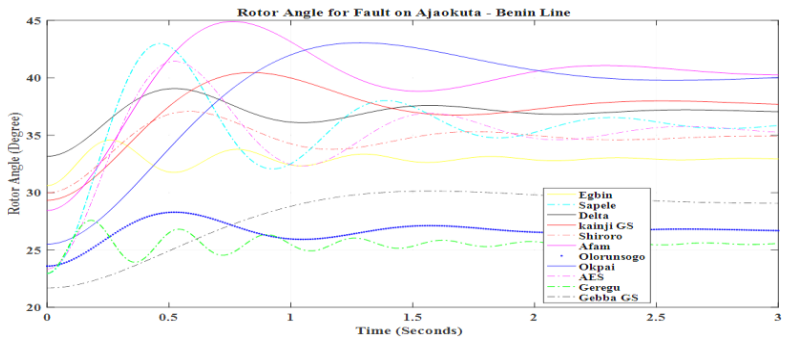

Fig 7.0: Rotor Angle response of the generators for fault clearing time of 0.5sec (with ANN Controlled VSC-HVDC)

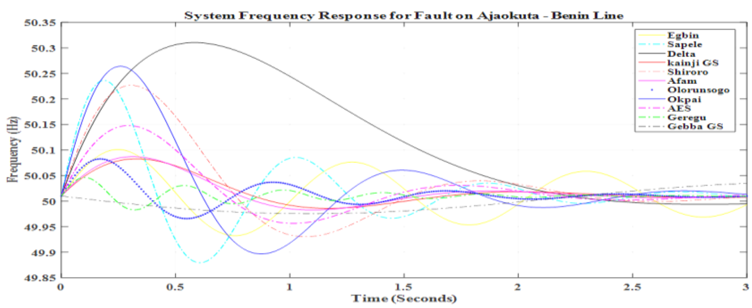

Fig 8.0: Frequency response of the system generators for fault clearing time of 0.5sec (with ANN Controlled VSC-HVDC)

In this Scenario. it can be observed that the oscillation of those five generators at Geregu, Sapele, Delta, Okpai and Afam buses which were most critically disturbed have achieved faster damping as shown in figure 7.0 and 8.0 with CCT of 0.2seconds.

Table 4.0: 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
2	Afam	1.000000	-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	-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

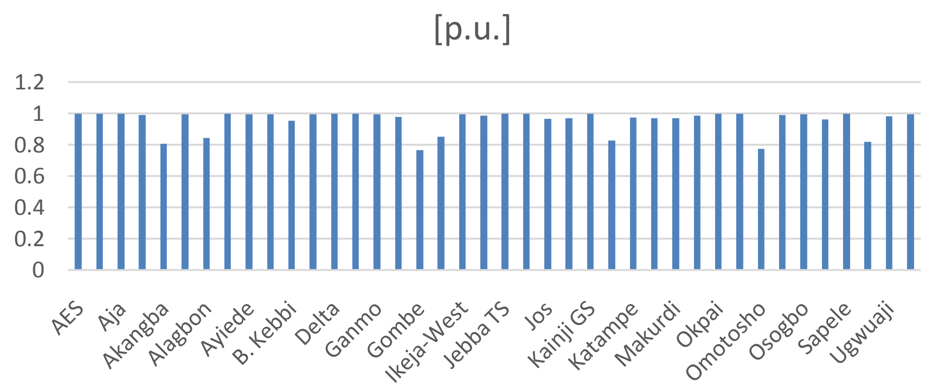

Figure 9.0: Nigeria 330kV Transmission Line Bus Voltage Profile During Occurrence of a Three Phase Fault on Ajaokuta Bus with ANN Controlled VSC-HVDC Installed

It can be observed from Table 4.0 that the voltage violations at buses 1, 2, 13, 16, 31, 32 and 37 were further improved.

CONCLUSION

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 location of a balanced 3-phase fault, at various nodes, were determined based on the most critical buses within the network through eigenvalue analysis and its damping ratio and the dynamic responses for various fault locations were obtained. The result obtained shows that when a 3-phase fault of any duration occurs on Markudi, Ajaokuta and Benin buses, the system losses synchronism immediately. Also, Jos - Markudi, Ajaokuta - Benin and Ikeja West - 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 dissertation has successfully demonstrated that the transient stability of the Nigeria 330kV transmission system can be significantly improved by applying an intelligent HVDC to the network.

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