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Enhancing Transient Stability of Nigeria 330kv Transmission Grid Using a High Voltage Direct Current (HVDC)

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Abstract- The Nigerian power network over the years has suffered incessant power interruptions caused by inadequacies in power generation capacity, inadequate transmission, distribution facilities and poor maintenance culture and other disturbances. Therefore, this paper presents the application of a VSC-HVDC system for the improvement of the transient stability of the Nigeria 330kV transmission network. First, the buses that are marginally unstable (critical buses) in the network were determined through eigen value analysis of the system buses. Then, a balanced 3-phase fault was applied to the few critical buses and lines of the transmission network. By observing the dynamic response of the generators in the Nigeria 330kV grid, the existing transient stability situation was determined. The finding obtained vividly revealed that buses Olorunsogbo and Omotosho are the two most critical buses while transmission lines from Ikeja West - Olorunshogo Generating Station (GS) and Omotosho - Benin TS within the network are the most critical transmission lines. Also, when the balanced 3-phase fault was applied to these mentioned critical buses and lines, the network loses synchronism. To solve the problem, VSC-HVDC was installed at the identified lines that are marginally unstable. The conventional PI method was used to control the parameters of the VSC-HVDC converter and the converter in MATLAB/PSAT environment. The results obtained showed that the fault critical clearing time (CCT) was increased from 300milli-seconds to 400milli-seconds which is 33.33% increment. Also, the oscillations were quickly damped.

I. INTRODUCTION

Power system researchers in the past decades have faced a major challenge with the enhancement of the dynamic response of generators within a power system, when subjected to different disturbances. These different disturbances have resulted in frequent transient instability on the grid network (Rani and Arul, 2013). The effect of this, in long-run, is frequent power failures, long outage durations, poor availability and sustained blackouts and system collapse. The negative impact of poor availability and sustained blackouts are high on power system operators and consumers of electricity. It results in high operation costs for operators, causes drop in quality of life of electricity consumers, increases cost of living, shuts down industries, causes loss of jobs, increases production cost and in general results in down turn in national economy. Resolving the challenge of frequent transient instability on our power networks will resolve the above stated problem and its consequences (Sagar, Pavan and Rajalakshmi, 2016). In this work, HVDC controlled by the conventional PID is proposed as a technique for improving the transient stability of the Nigerian 40 bus network. The proposed method will enhance the transient stability of the network by intelligently controlling active and reactive power balance in the network and allowing bulk power transfer of power where it is mostly needed.

Recently, the demand for electricity has radically increased and a modern power system becomes a difficult network of transmission lines interconnecting the generating stations to the major load 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 security of a power system is regarded as the ability of the network to withstand disturbances without breaking down (Karthikeyan and Dhal, 2015). The complicated network causes the stability problem. Stability is determined by the observation of voltage, frequency and rotor angle. One of the indices to assess the state of security of a power system is the transient stability (Ayodele, Ogunjuyigbe and Oladele, 2016) and it involves the ability of power system to remain in equilibrium or return to acceptable equilibrium when subjected to large disturbances (Ayodele, Jimoh, Munda and Agee, 2012). Transient stability examines the impact of disturbance in power systems considering the operating conditions. The analysis of the dynamic behavior of power systems for the transient stability gives information about the ability of power system to sustain synchronism during and after the disturbances.

The implication of the power system becoming more complicated, is that the fault current becomes huge once fault occurs, hence this makes problems associated with power system transient stability becoming more severe. This fault current can considerably be limited or reduced by the use of FLC elements and invariably improve the transient stability of the power network (Masaki and Junji, 2010). However, some researchers argue that superconductor fault current limiter (SFCL) is more effective in limiting or reducing fault currents upon occurrence of fault. This could be attributed to the fact that SFCL does not get involved during steady state network operation because it gives low impedance, almost zero, during normal operation. The superconductor fault current limiter causes a quick rise in the limiter impedance to a value necessary for the fault current to be limited through its (SFCL) quenching mechanism. The power network transient stability could be improved by the risen impedance of the SFCL (Sagar, Pavan, and Rajalakshmi, 2016). The application of superconductor fault current limiter in a power network can therefore enhance the distributed energy qualities and stability of the power system (Sravani, Hari, and Basha, 2010). Stability studies are helpful for the determination of critical clearing time of circuit breakers, voltage levels and a transfer capability of the systems.

The controllability of the HVDC power is often used to improve the operating conditions of the AC network where the converter stations are located. HVDC allows more efficient bulk power transfer over distances. However, cost is important variable in the equation. Once installed, HVDC transmission systems are integral part of the electrical power system, improving stability, reliability and transmission capacity. High Voltage Direct Current (HVDC) power transmission is employed to move large amounts of electric power. There are several possibilities to enhance the transient stability in a power system. One adequate option is by using the high controllability of the HVDC if HVDC is available in the system (Hua, Tian-gang, Mu-Zi and Zhi-min, 2012). The strategy controls the power through the HVDC to help make the system more transient stable during disturbances. Loss of synchronism is prevented by quickly producing sufficient decelerating energy to counteract accelerating energy gained. The power flow in the HVDC link is modulated with the addition of an auxiliary signal to the current reference of the rectifier firing angle controller. This modulation control signal is derived from speed deviation signal of the generator utilizing a PD controller; the utilization of a PD controller is suitable because it has the property of fast response. It has been demonstrated that the power flow in the HVDC link is modulated by the addition of an auxiliary signal to the current reference of the rectifier firing angle controller to enhance the transient stability in power system. The proportional, integral and derivative (PID) controller works well and damps the first swing oscillation transient so the system remains stable (Eriksson, 2014). 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.

II. THE CONCEPT OF HVDC TECHNOLOGY

The principal interaction that happens in a HVDC network is the transformation of electrical flow from AC to DC (rectifier) at the sending end, and from DC to AC (inverter) at the receiving end. There are three different ways of accomplishing transformation

(Bandaru, Dhawa, Chatterjee and Bhattacharya, 2018):

- Natural Commutated Converters.

Natural commutated converters are generally utilized in the HVDC networks in this modern time. The device that permits this transformation process is the thyristor, which is a controllable semiconductor that can convey exceptionally high current flows (up to 4000A) and can hinder extremely high voltages (up to 10kV). Through interfacing the thyristors in series, it is feasible to develop a thyristor valve, which can work at extremely high voltages (a few hundred of kV). The thyristor valve is worked at net frequency (50Hz or 60Hz) and through a control angle it is feasible to change the DC voltage level of the extension. This capacity is the way by which the transmitted power is controlled quickly and proficiently.

- Capacitor Commutated Converters (CCC).

An improvement in the thyristor-based commutation, the CCC idea is portrayed by the utilization of substitution capacitors embedded in series between the converter transformers and the thyristor valves. The compensation capacitors further develop the commutation failure execution of the converters when connected with feeble systems.

- Forced Commutated Converters.

This kind of converters presents a range of benefits, for example feed of feed of passive (without generation), that is not dependent of reactive and active power, and power quality control. The valves of these converters are developed with semiconductors with the capacity not exclusively to turn-on yet in addition to turn off. They are known as VSC (Voltage Source Converters). Two kinds of semiconductors are regularly utilized in the voltage source converters: the GTO (Gate Turn-Off Thyristor) or the IGBT (Insulated Gate Bipolar Transistor). The two of them have been in continuous use in mechanical applications since mid-eighties. The VSC commutates with high recurrence (not with the net recurrence). The activity of the converter is accomplished by Pulse Width Modulation (PWM). With PWM it is feasible to make any stage 3 angle or amplitude (up to a specific limit) by changing the PWM design, which should be possible quickly (Björk, 2019). Along these lines, PWM offers the likelihood to control both reactive and active power freely. This makes the PWM Voltage Source Converter a near ideal device in the transmission system. From a transmission network perspective, it goes about as a motor or generator without mass that can handle reactive and active power immediately.

III. ANALYSIS OF THE TRANSIENT STABILITY OF THE NIGERIA 330KV NETWORK AND ITS WEAKEST BUSES

To ensure that the buses to install the VSC-HVDC 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. By clicking on the eigenvalue analysis button on the PSAT, the transient stability of the network was analyzed from the result obtained. The output from the eigenvalue analysis by the PSAT model of the Nigeria 330kV transmission grid was extracted and tabulated in Table 1.

3.1 Mathematical Derivation of Swing Equation for a Multi- Machine Power System

If we consider a multi-machine *n*-bus power network consisting of *m* number of generators such that *n* >*m*. Then at any bus *I* within the network, the complex voltages (V_i), real power of the generator (P_{gi}) and the reactive power of the generator(Q_{gi}) can simply be gotten from the pre-fault load-flow analysis from which the initial machine voltages (E_i) can also be gotten. This relationship can be communicated as (Sravani, Hari, and Basha, 2010):

$$E_i = V_i + jX_i\left[\frac{P_{gi}-jQ_{gi}}{V_i^*}\right] \qquad (1)$$

where;

X_i is the equivalent reactance at bus i. By transforming each load bus into its equivalent constant admittance form, we have

$$Y_{Li} = \frac{P_{Li}-jQ_{Li}}{|V_i|^2} \qquad (2)$$

Where $P_{Li}$and $Q_{Li}$are the equivalent real and reactive powers respectively at each load buses. The pre-fault bus admittance matrix [*bus Y*] can therefore be formed with the inclusion of generators reactance and the converted load admittance. This can be partitioned as (Sravani, Hari, and Basha, 2010):

$$Y_{bus} = \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} \quad (3)$$

Where Y_{11}, Y_{12}, Y_{21}, and Y_{22} are the sub-matrices of Y_{bus}. Out of these four sub-matrices, Y_{11}, whose dimension is $m \times m$is the primary interest here as it contains generators buses just with the load buses disposed of. Equation (3) is formulated for the system states such as pre-fault, during fault and post-fault. The *bus Y* for the system is then derived by disposing all nodes except the internal generator nodes. The decrease is accomplished dependent on the fact that injections at all load nodes are zero. The nodal equations, in smaller form, can thusly be communicated as (Sharma, and Hooda, 2012):

$$\begin{bmatrix} 1 \\ 0 \end{bmatrix} = \begin{bmatrix} Y_{mm} & Y_{mn} \\ Y_{nm} & Y_{nn} \end{bmatrix} \begin{bmatrix} V_m \\ V_n \end{bmatrix} \quad (4)$$

By expansion equation (3.4) can be expanded as

$$I_m = Y_{mm}V_m + Y_{mn}V_n \quad (5)$$

And

$$0 = Y_{nm}V_m + Y_{nn}V_n \quad (6)$$

By combining equations (5) and (6) and some mathematical manipulations, the desired reduced admittance matrix can be obtained as

$$Y_{reduced} = Y_{mm} - Y_{mn}Y_{nn}^{-1}Y_{nm} \quad (7)$$

$Y_{reduced}$ is the desired reduced matrix with dimension m x m, where m is the number of generators. The output power of each machine can then be stated as (Machowski, Kacejko, Nogal and Wancerz 2013):

$$P_{ei} = E_i^2 Y_{ii} \cos\theta_{ii} + \sum_{\substack{i=1 \\ j\neq 1}}^{m} |E_i||E_j||Y_{ij}| \cos\left(\theta_{ij} - \delta_i + \delta_j\right) \quad (8)$$

Equation (3.8) can then be employed to calculate the system during fault $P_{ei}(P_{ei(during-fault)})$ and post-fault $P_{ei}(P_{ei(post-fault)})$ conditions. The rotor dynamics, representing the swing equation, at any bus i, is written by (Sharma, and Hooda, 2012):

$$\frac{H_i}{\pi f_0}\frac{d^2\delta_i}{dt^2} + D_i\frac{d_i}{dt} = P_{mi} - P_{ei} \quad (9)$$

All the parameters assume their normal meanings. If we examine a case when there is no damping, that is $D_i = 0$, equation (9) can be transformed as

$$\frac{H_i}{\pi f_0}\frac{d^2\delta_i}{dt^2} = P_{mi} - \left(E_i^2 Y_{ii}\cos\theta_{ii} + \sum_{\substack{i=1 \\ j\neq 1}}^{m} |E_i||E_j||Y_{ij}| \cos\left(\theta_{ij} - \delta_i + \delta_j\right)\right) \quad (10)$$

The swing equation for the during-fault condition can simply be communicated as

$$\frac{H_i}{\pi f_0}\frac{d^2\delta_i}{dt^2} + D_i\frac{d_i}{dt} = P_{mi} - P_{ei(during-fault)} \quad (11)$$

Similarly, the swing equation for the post fault condition can also be communicated as

$$\frac{H_i}{\pi f_0}\frac{d^2\delta_i}{dt^2} + D_i\frac{d_i}{dt} = P_{mi} - P_{ei(post-fault)} \quad (12)$$

3.2 Eigen value Analysis

The Eigen value 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 ($\boldsymbol{\gamma}$) 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 (Eleschová, Smitková and Beláň, 2010). The damping ratio (τ) is an indication of the ability of the system to return to stable state in the event of disturbance.

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 paper to explore the peculiarity of the Nigerian power system. Table 1 shows the output from the Eigen value analysis on the PSAT model of the Nigeria 330kV transmission grid. It can be seen that the network is generally not stable.

This is due to the fact that all the Eigen values are not located on the left side of the S-plane. The Eigen values located on the left side of the S-plane are negative (stable) whereas Eigen values located on the right side of the S-plane are positive (unstable). However, not all the buses in the power system are part of the instability. Among all the buses whose Eigen values are located on the right side of the S-plane, the most unstable buses would be selected for application of three phase fault for the evaluation of the system transient stability improvement using ANN controlled VSC-HVDC. The buses located on the right side of the S-plane are unstable buses but since two buses are to be selected, the damping ratio is used as the criterion for the selection. The lower the damping ratio, the more unstable the bus would be.

From the Table 1, the buses selected are Olorunsogo – bus 32 and Omotosho – bus 33. The Eigen values of these buses are $0.2562 \pm j4.7324$ and $2.7297 \pm j5.5635$ with damping ratios of 0.0574 and 0.0384 respectively. The eigenvalues of these buses are located on the right side of the S-plane and they are the buses with the lowest damping ratio. These selected buses 32 and 33 were now subjected to a three phase faults one after the other whereas the loads at buses were held constant at the demand values.

Table 1: Extracted output from Eigen value analysis in PSAT environment

Bus Number	Bus Name	Eigen Value (γ)	Damping Ratio (τ)	Participation Factor (%)
1	AES	$1.7653 \pm j10.4192$	0.4427	2.2076
2	Afam	$-1.7011 \pm j3.1375$	0.3442	0.0768
3	Aja	$-2.1746 \pm j6.7011$	0.2632	0.7139
4	Ajaokuta	$-1.9640 \pm j5.3208$	0.6412	2.6122
5	Akangba	$2.0367 \pm j8.2287$	0.5941	0.6122
6	Aladja	$-3.4083 \pm j7.5374$	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	$1.7301 \pm j3.1375$	0.2193	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	$3.4083 \pm j7.5374$	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	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	$1.4011 \pm j3.1375$	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	$-1.9640 \pm j5.3208$	0.6412	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	$0.2562 \pm j4.7324$	0.0574	3.4165
33	Omotosho	$2.7297 \pm j5.5635$	0.0384	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	$0.1674 \pm j4.1170$	0.0751	6.3228
39	Ugwuaji	$-1.6064 \pm j6.8320$	0.8232	3.1297
40	Yola	$-2.0367 \pm j8.2287$	1.7624	1.1096

IV. HVDC CONTROL AND PROTECTION

The rectifier is equipped with a current controller to maintain the HVDC system current constant. The HVDC system current at the rectifier end is measured with the proper transducer and pass through the appropriate filters. After filtering, the measured current is compared to the reference current to produce the error signal. The error signal from the rectifier side, then passes through the conventional PI controller to produce firing angle order. The firing circuit which is synchronized with the AC system through phase locked loop uses the firing angle order to produce the necessary equidistant pulses for the rectifier valves.

Similarly, the inverter is provided with a current controller to maintain the HVDC system current constant and a gamma controller for maintaining a constant extinction angle. The HVDC system current at the inverter end is measured with the proper transducer and pass through the appropriate filters. After filtering, the measured current is compared to the reference current to produce an error signal. The error signal from the inverter side, then passes through the conventional PI controller to produce firing angle order. For gamma controller the gamma value is measured using zero crossing information from the commutation bus voltages and the valve switching times. The gamma error is applied to another conventional PI controller, which produce the firing angle order for the inverter. The firing angle orders of the current and gamma controller are compared and the minimum is used to produce the firing pulses for the inverter valves.

The reference current for the current controllers is obtained from the master controller output through the voltage dependent current order limiter (VDCOL) which can reduce the reference value of direct current (I_{dref}) in case of the large decline in direct voltage, so as to suppress the over current and maintain the system voltage. In normal state, there is a small margin (I_{dmarg}) between the direct current references of the two current controllers. Since I_{dref}f of inverter will be smaller than I_{dref} of rectifier, the output of the current controller configured in the inverter side will be regulated to its maximum, and thus the current controller will not be selected among the two controllers (current and gamma). Therefore, the gamma controller will decide the inverter's firing angle.

HVDC protection functions are implemented to protect the rectifier and the inverter. The HVDC fault protection circuit at the rectifier detects and force the delay angle into the inverter region so as to quench the fault current. The commutation failure prevention, control circuit of the inverter detects various AC faults and reduces the utmost delay angle limit in order to decrease the risk of commutation failure. The low AC voltage detection circuit at the rectifier and the inverter serves to categorize between an AC fault and a DC fault.

V. INSTALLATION OF THE HVDC AT CRITICAL BUSES IN THE TEST CASE NETWORK

The HVDC system was installed on the two most critical buses in the Nigeria 330kV network Load flow on the entire system was performed thereafter a three-phase fault was introduced on the same buses and the result was studied. The buses on which the HVDC are installed are Olorunsogbo and Omotosho buses as explained above. The swing equations are solved to obtain the network conditions for post-fault (see Section 3.1) using numerical solver ode45. The numerical solver, ode45, which is a built-in MATLAB/PSATS function, is employed in solving the *m*-number of swing equations within the system.

Figures 1 and 2 show the PSAT Model of the Nigeria 330kV transmission power system with VSC-HVDC installed along side with Olorunsogbo – Ikeja West and Omotosho – Benin Transmission Lines respectively. The position for the location of the VSC-HVDC was determined through Eigen value analysis as aforementioned.

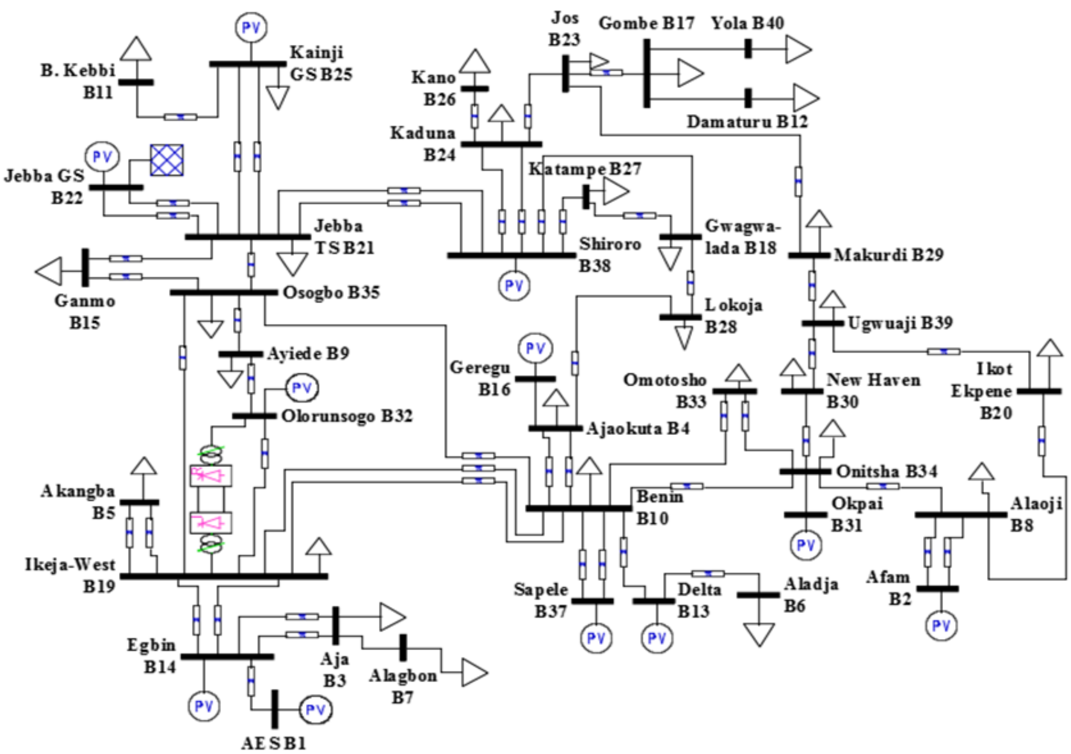

Figure 1: PSAT Model of the Nigeria 330kV transmission power system with VSC-HVDC installed along side with Olorunsogbo – Ikeja West Transmission Line

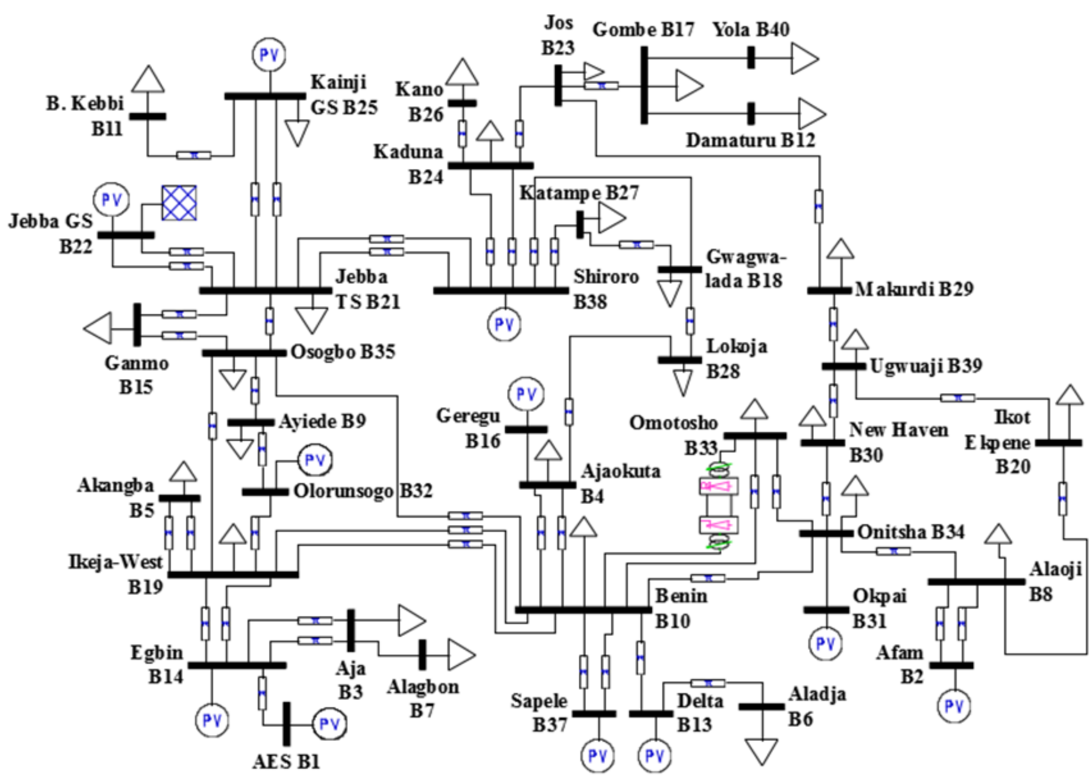

Figure 2: PSAT Model of the Nigeria 330kV transmission power system with VSC-HVDC installed along side with Omotosho – Benin Transmission Line

VI. RESPONSE OF THE NIGERIA 40 BUS 330KV TRANSMISSION NETWORK TO OCCURRENCE OF FAUL

In this paper, two cases as aforementioned were considered for the transient stability analysis on the Nigeria 330-kV grid network.

6.1 Case One: Three Phase Fault at Olorunsogbo Bus

A three-phase fault was made on Olorunsogbo bus (Bus 32) with line Olorunsogbo – Ikeja West (32-19) removed, in this case. 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 plot of the power angle curves and the frequency responses of the eleven generators in the system during a transient three-phase fault on Olorunsogbo to Ikeja West transmission line. It can be observed that generators at Olorunsogbo, Egbin, Delta and Sapele buses were most critically disturbed and failed to recover after the fault was cleared at 0.3seconds. These four generators in the system lost synchronism and became unstable as shown in Figures 3 and 4. Remember, the critical clearing time (CCT) is stated as that maximum time that a fault can stay before it is removed, without causing loss of synchronism and it is commonly employed as a transient stability margin indicator.

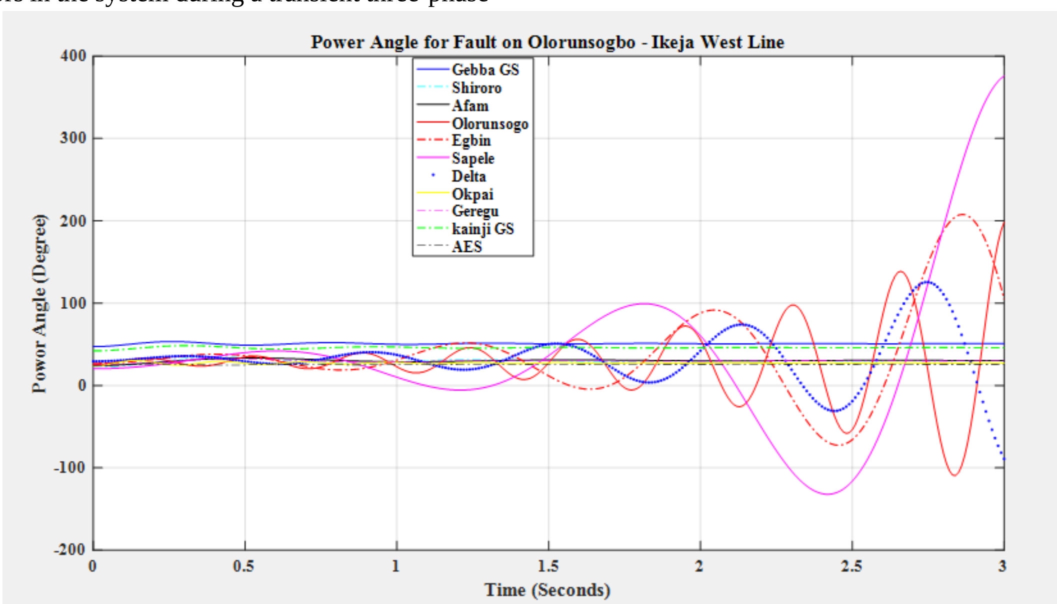

Figure 3: Power Angle response of the generators for fault clearing time of 0.3sec (without any VSC-HVDC)

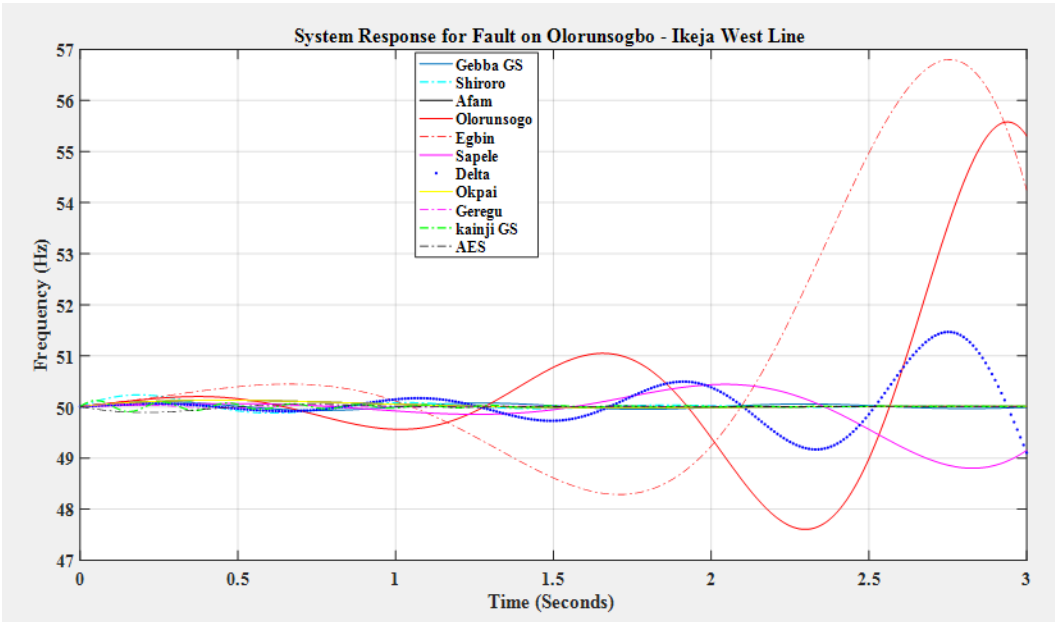

Figure 4: Frequency response of the system generators for fault clearing time of 0.3sec (without any VSC-HVDC)

6.2 Case Two: Three Phase Fault at Omotosho Bus

In this case, a three-phase fault was made on Omotosho bus (Bus 33) with line Omotosho – Benin (33-10) removed. Figures 5 and 6 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 Omotosho to Benin transmission line. It can be observed that generators at Olorunsogbo, AES, Geregu, Okpai, Afam, Delta and Sapele buses were most critically disturbed and failed to recover after the fault was cleared at 300 milliseconds. These seven generators in the system lost synchronism and became unstable as shown in Figures 5 and 6.

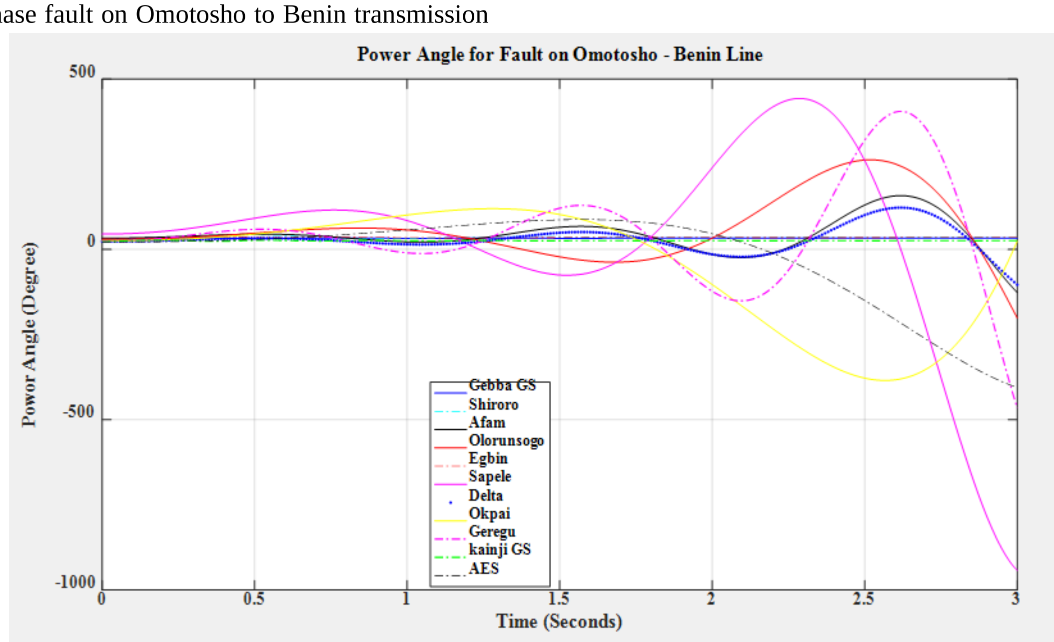

Figure 5: Power Angle response of the generators for fault clearing time of 0.3sec (without any VSC-HVDC)

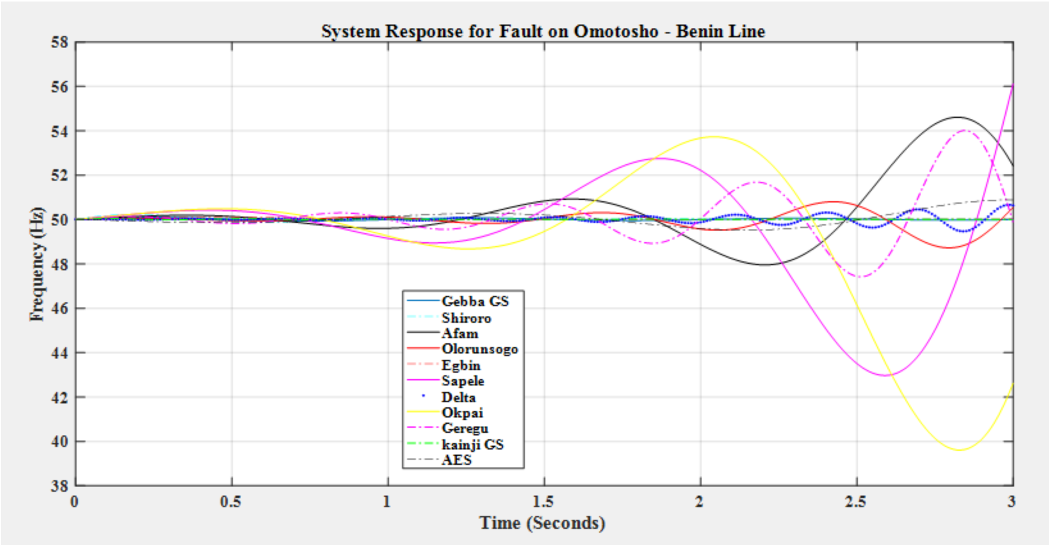

Figure 6: Frequency response of the system generators for fault clearing time of 0.3sec (without any VSC-HVDC)

VII. RESPONSE OF THE NIGERIA 330KV TRANSMISSION GRID TO OCCURRENCE OF FAULT WITH HVDC INSTALLED AT THE UNSTABLE BUSES

The VSC-HVDC was controlled by the convectional PI method. As aforementioned, the simulations are implemented 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.

7.1 Case One: Three Phase Fault at Olorunsogbo Bus

In this case, a VSC-HDVC was now installed in complementary or addition to Olorunsogbo – Ikeja West transmission line. As before, a three-phase fault was created on Olorunsogbo bus (Bus 32) with line Olorunsogbo – Ikeja West (32-19) 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 7 and 8 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 Olorunsogbo to Ikeja West transmission line. It can be observed that those four generators at Olorunsogbo, Egbin, Delta and Sapele 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 attributed to the fact that the VSC-HVDC was able to inject enough power in the two buses (Bus 32 - 19). Hence, with the HVDC in the system the transient stability of the system has been improved as can be seen from Figures 7 and 8 respectively.

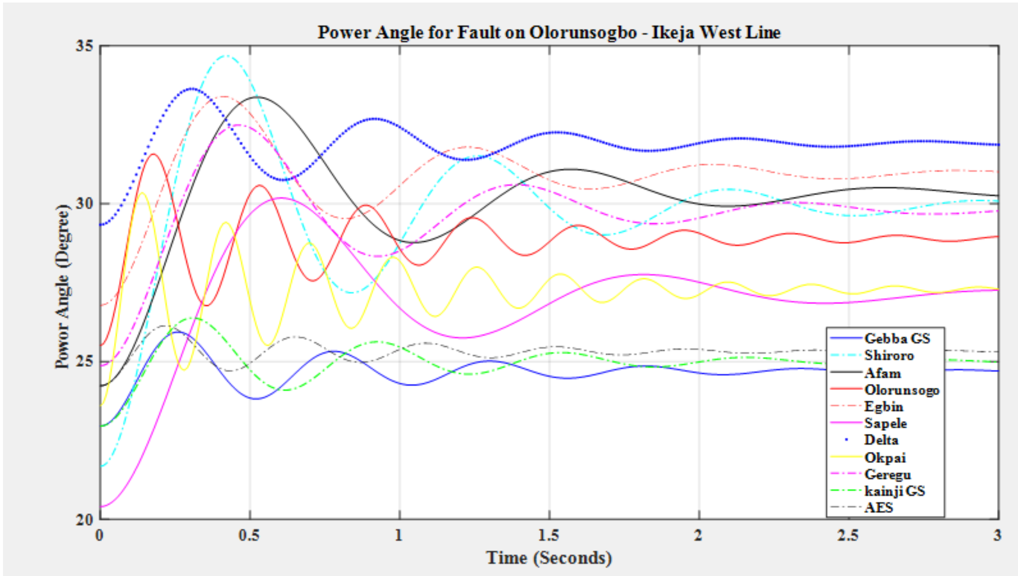

Figure 7: Power Angle response of the generators for fault clearing time of 0.3sec (with only VSC-HVDC)

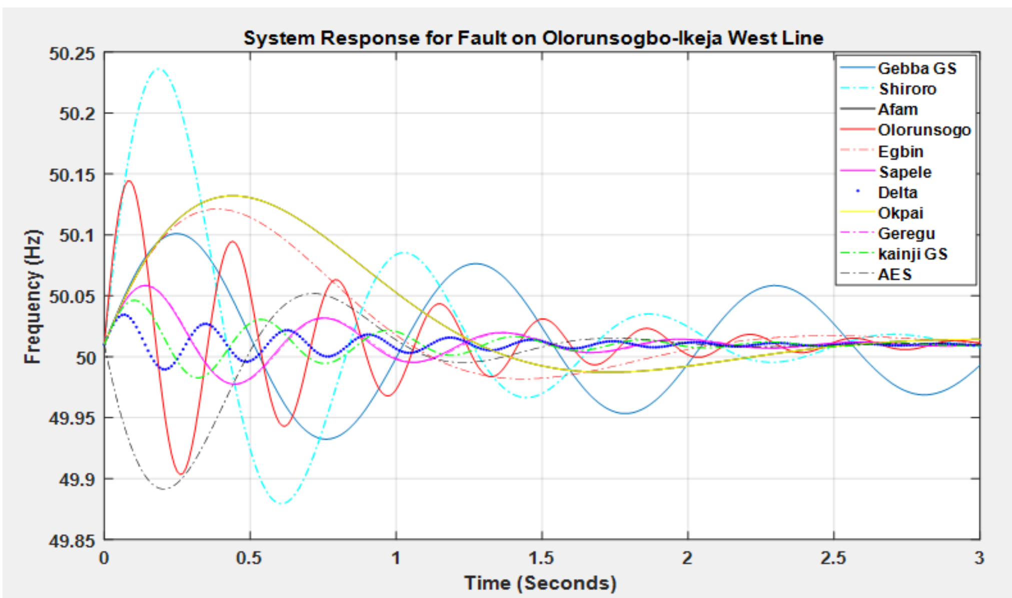

Figure 8: Frequency response of the system generators for fault clearing time of 0.3sec (with only VSC-HVDC).

7.2 Case Two: Three Phase Fault at Omotosho Bus

In this case, a VSC-HDVC was now installed in complementary or addition to Omotosho – Benin transmission line. As before, a three-phase fault was made on Omotosho bus (Bus 33) with line Omotosho – Benin (33 - 10) removed, by the circuit breakers (CBs) at both ends opening to remove the faulted line from the system. Figures 9 and 10 show the active responses of the generators for critical clearing time of 300ms.

Figures 9 and 10 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 Omotosho to Benin transmission line. It can be observed that those generators at AES, Olorunsogbo, Geregu, Okpai, Afam, Delta and Sapele 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. Which again, is attributed to the fact that the VSC-HVDC was able to inject enough power in the two buses (Bus 33 - 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 power angle of the system generators in Figures 9 and 10 respectively.

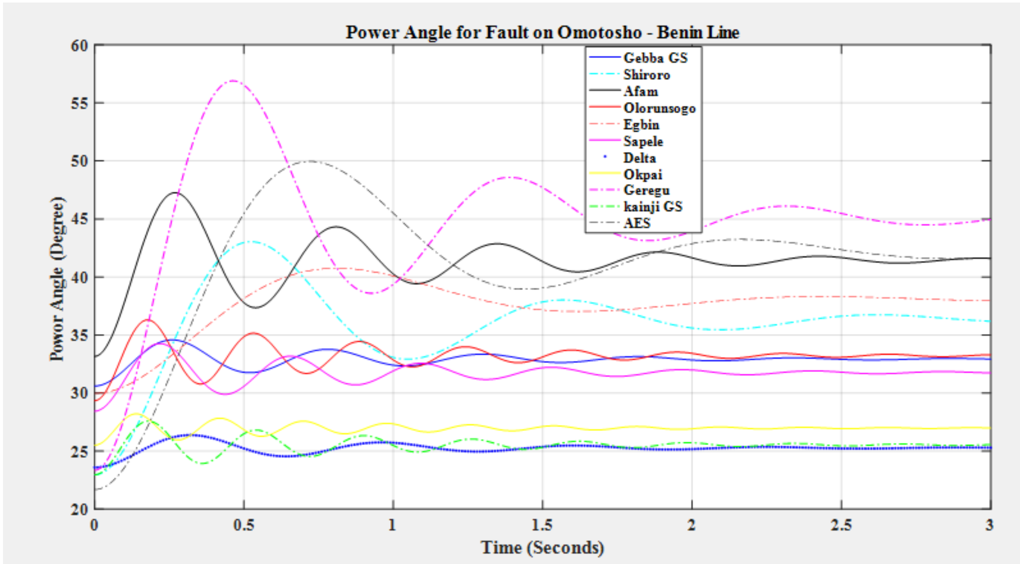

Figure 9: Power Angle response of the generators for fault clearing time of 0.3sec (with only VSC-HVDC)

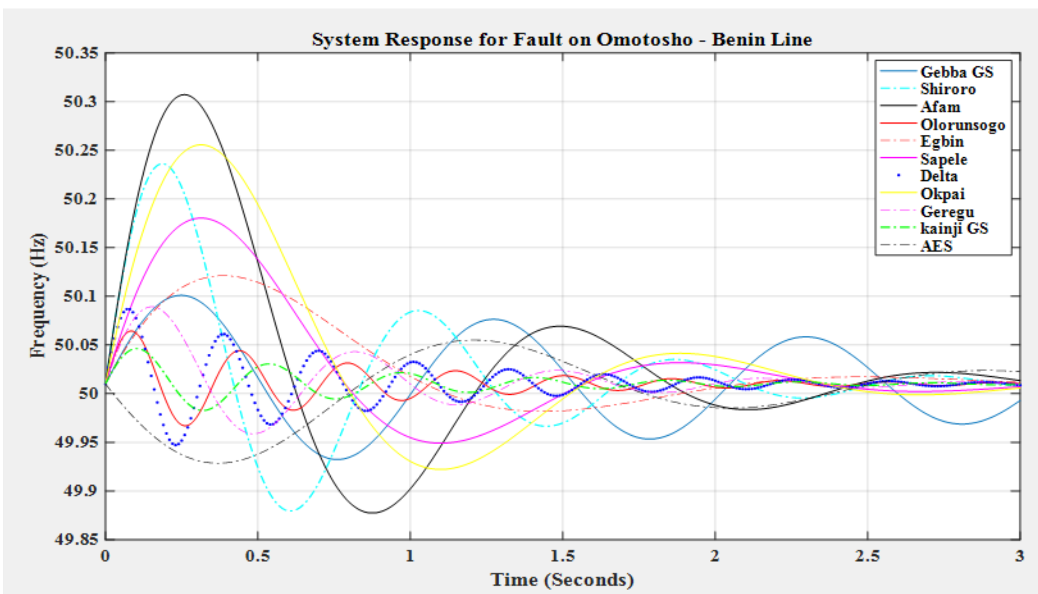

Figure 10: Frequency response of the system generators for fault clearing time of 0.3sec (with only VSC-HVDC)

CONCLUSION

In this work, transient stability improvement of the Nigeria 330-kV network utilizing smart VSC-HVDC has been done. The numerical formulations for the investigation are introduced. A balanced fault location, at different nodes was dependent on the most disadvantaged buses inside the system which was arrived at through Eigen value investigation. The dynamic reactions for different disturbance locations are gotten. The outcomes acquired show that the Nigeria 330-kV transmission network is by and by working on a delayed bomb alert state which could prompt all-out power outage if a 3-phase fault happens on some vital buses. The result gotten shows that when a 3-phase disturbance of any span happens on Olorunsogbo and Omotosho buses, the network will lose synchronism right away. Additionally, Benin - Oomotosho and Olorunsogbo – Ikeja West transmission lines have been recognized as basic lines that can energize instability in the power network whenever eliminated to clear a 3-phase disturbance.

Henceforth, the requirement for measures that will further develop transient stability like the installing of FACTS devices into the transmission system, utilization of effective circuit breakers, utilization of breaking resistors at generator buses, short circuit limiters, etc. to stay away from all out-network breakdown, if a 3-phase fault happens on the previously mentioned critical buses or transmission lines. HVDC as a FACTS device has been utilized to work on the transient stability of the network. The HVDC was keenly controlled utilizing artificial neural network.

The inverter and the converter boundaries of the HVDC were constrained by the customary PI method and artificial neural network. The outcomes got showed that fifty percent transient stability improvement was accomplished when the HVDC was controlled with the artificial neural network as can be seen by noticing the dynamic reaction of the generators in the Nigeria 330-kV system. The summed-up swing condition for a multi-machine power network was introduced. The entire simulation of the Nigeria 330kV transmission network was done in MATLAB/PSAT environment.

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