Analysis And Simulation of High Voltage Alternating Current Connectivity of Afam-Bonny Island

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Abstract- The analysis and simulation of the actual equipment performance on high voltage alternating current connectivity of Bonny Island through Bodo-Ogoni to Afam independent power project (IPP), Rivers State, Nigeria. Necessary data on power transformers and the route length of the network was considered, the determination of the transformer current, the transformer loading, the active power, the reactive power, the apparent power, the complex power, the power factor and the phase voltage on each transformer on the network. Determine the Bus bar current, the cable size, conductor resistance, the cross-sectional area of the conductor, the voltage drops on each Buses, and the resistance of line per Kilometre were also determined. Voltage stability technique was use in the implementation of the network. Electrical transient analyzer program (ETAP 19.0.1) simulation software was used in designing the network. Apply Newton-Raphson method was utilized for the achievement of the optimal load flow of the network.

Indexed Terms- Bus bar, Conductor, Electrical Transient Analyzer Program (ETAP) Software, power transformers and Voltage stability technique.

I. INTRODUCTION

Electricity in Nigeria is still predominantly powered by alternating current and methods are now available for converting direct current to higher and lower voltages, power transmission lines facilitate the bulk transfer of electricity from generating station to local distribution network using high voltage direct current (HVDC) or high voltage alternating current (HVAC) transmission system from a remote generating station to the load center. According to [1], the increase in power demand of electricity bulk power has pushed the power transmission network to its maximum limits and beyond, resulting in shortening the life span of the network or total collapse. In the views of [2], the Nigerian 330kV transmission grid system is characterized by high power losses due to long transmission lines. In the perspective of [3], the unbundling neck of the Nigerian existing power transmission network (the 11,000km, 330kV transmission lines) are faced with so many problems such as; Inability to effectively dispatch generated energy to meet the load demand, a large number of uncompleted transmission line projects, reinforcement and expansion projects in the power industry, poor voltage profile in most of the grid network, the inability of the existing transmission lines to wheel more than 4000MW of power at present, operational problems and voltage frequency control. [4], said this same transmission system has the capacity to transmit a maximum of about 4,000MW and it is technically fragile and radial in nature thus very sensitive to major disturbances and does not cover every part of the country. The investigation of the actual equipment performance on high voltage alternating current connectivity from Afam independent power project (IPP) to Bonny Island, Rivers State, Nigeria was the case study. The following objectives were considered to: Obtain the necessary data on power transformer and the route length from Afam IPP generating station to Bonny Island. Determine the transformer current, the transformer loading, the active power, the reactive power, the apparent power, the complex power, the power factor and the phase voltage on each transformer on the network. Determine the Bus bar current, the cable size, conductor resistance, the cross sectional area of the conductor, the voltage drop on each Buses, the resistance of line per Kilometre, Voltage stability technique was use in implementing the Afam IPP–Bonny Island transmission network to the national grid for analysis. Electrical transient analyzer program (ETAP 19.0.1) simulation software was used in designing the network. Apply Newton-Raphson method was utilized for the achievement of the optimal load flow of the network.

II. HIGH VOLTAGE ALTERNATING CURRENT TRANSMISSION LINE IN NIGERIA

The first 132kV power interconnection link in Nigeria was constructed in 1962 between Logos and Ibadan [5]. In 1968, the first National grid structure emerged with the construction of the Kainji hydro station which supplied power via a 330kV, primary radial type transmission network into the three 132kV sub system, existing in the Western, Northern and Eastern parts of the country [6]. In the perspective of [7], the central control for the 330kV network was coordinated from Kainji power supply control room, while the 132kV network was run by load dispatcher located at Ijora power supply Lagos. According to [8], the radial transmission grid (330kV and 132kV) was managed by the Transmission Company of Nigeria (TCN), with the responsibility of undertaking the system operation and market settlement functions, respectively. These networks are characterised by many disturbances, which cause various hindrances and outages [9]. The current transmission system in Nigeria comprises 5523.8km of 330kV, 6801.49km of 132kV, and 32No of 330/132kV substations with total installed transformation capacity of 7688MVA. 105No. 132/33/11kV substations with total installed transformation capacity of 9130MVA. The average available capacity on 330/132kV is 7364MVA and 8448MVA on 132/33kV [10].

The existing grid lacks the technical adequacy to handle huge electric power injection and meet the future system performance criteria [11]. The grid interconnects these stations with fifty-two buses and sixty-four transmission lines of either dual or single circuit lines and has four control centres (one national control centre at Osogbo and three supplementary control centres at Benin, Shiroro and Egbin) [12]. The 28-bus 330kV transmission system of Nigeria consist of ten generating stations, twenty-three load stations and thirty-two transmission lines, divided into three major regions: North, South-East and South-West regions, the North region is connected to South by a triple circuit lines between Jebba and Osogbo, while West is linked to the East through one transmission line from Osogbo to Benin and a double circuit line from Ikeja to Benin [13].

III. MATERIALS AND METHODS

The materials used were synchronous generator, power transformers, line voltage, HVAC transmission line, Bus-Bar, Lump load, and GPS were used in determining the route length of the network. Voltage stability technique was formulated and implemented with Newton-Raphson method for the performance study of the Optimal Load flow analysis of the network. Electrical Transient Analyzer Program (ETAP) simulation software was used to achieved the designed network as shown in Figure 1.

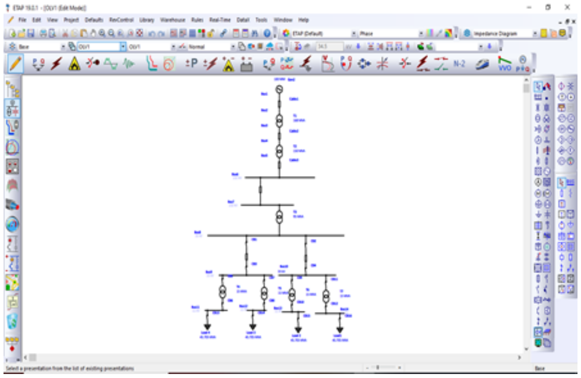

Figure 1: The Bonny Island HVAC Connected to Network National Grid

- Determination of the Generator Parameter

- Determination of the Generator Real Power (MVA) on Network.

converting the generator real power (100MW) to megavolt-ampere (MVA), the power factor of 0.85 was considered we have

$$MVA = \frac{MW}{pf} \qquad (1)$$

Where, MW represent the megawatt value of the system and pf represents the power factor of 0.85

In determining the generator current on the network, we have

$$\text{Current } I = \frac{P(MVA)}{\sqrt{3} I V_L} \qquad (2)$$

Current with its safety factor

$$I = \frac{P(MVA)}{\sqrt{3}V_L} \times Safety\ Factor \tag{3}$$

Inputting the Generator current values in (3) into (4) for determining the generator loading, we have

$$\text{Generator loading MVA} = \sqrt{3}IV_L \tag{4}$$

- Generator Active Power (MW) Determination on the Network

Inputting the determine valve of the generator loading in (4) into (5) to determine the generator active power on the network, we have

$$\text{Active power in MW} = \sqrt{3}IV\cos\theta \tag{5}$$

- Generator Reactive Power (MVAR) Determination on the Network

Inputting the determine valve of the generator loading in (4) into (6) to determine the generator active power, we have

$$\text{Reactive power in MVAR} = \sqrt{3}VI\sin\theta \tag{6}$$

- The Determination of the Generator Apparent power in VA or MVA on the Network

Inputting the value of the active power (MW) and the reactive power (VAR or MVAR) in (5) and (6) into (7) in determining the value of the generator apparent power, we have

$$\text{Apparent power in MVA} = \sqrt{\text{MW}^2 + \text{MVAR}^2} \tag{7}$$

- The Determination of the Generator Complex Power (S) on the Network

Inputting the generator active power and generator reactive power value in (5) and (6) into (8) to determine the generator complex power, we have

$$\text{Complex power, } S = P + JQ \tag{8}$$

- The Analysis of Power Transformers on the Network.

Determination of the Input/Output Power (MVA) on each Transformer on the Network.

Equation (3) was used in determining the primary and secondary current rating on each transformer on the network. The transformer current values were inputted into (4) to determine the value of the transformer loading (MVA) on each transformer on the network.

- Determination of the Input/Output Active Power (MW) on each Transformer on the Network.

The determined transformer loading (MVA) values was inputted into (5) to determine the active power on each transformer on the network, we have

$$\text{Active power in watts or MW} = \sqrt{3}IV\cos\theta$$

- Determination of Input/Output Reactive Power (VAR or MVAR) on each Transformer on the Network

The transformer loading (MVA) values was inputted into (6) in determining the value of reactive power on each transformer on the network, we have

$$\text{Reactive power in VAR or MVAR} = \sqrt{3}VI\sin\theta$$

- The Determination of the Input/Output Apparent power in VA or MVA on each Transformer on the Network.

The active power (MW) and the reactive power (VAR or MVAR) values on each transformer on the network were inputted into (7), to determine the apparent power value on each transformer on the network, we have

$$\text{Apparent power in VA or MVA} = \sqrt{\text{MW}^2 + \text{MVAR}^2}$$

- The Determination of the Input/Output Complex Power (S) on each Transformer on the Network

The active power and reactive power values were inputted into (8) in determining the complex power value on each transformer on the network, we have

Complex power, S = P + JQ

- The Determination of the Input/Output Power Factor on each Transformer on the Network

The active power (MW) and the apparent power (MVA) values on each transformer on the network was inputted into (9), to determine the power factor values on each transformer on the network, we have

$$\text{Power factor, } \cos\theta = \frac{\text{Active power}}{\text{Apparent power}} = \frac{\text{MW}}{\text{MVA}}$$

- Determination of Phase Voltage

Equation (10) were used in determining the phase voltage on each transformer winding connected in star on the network as follows

$$\text{Phase voltage} = \frac{\text{line voltage}}{\sqrt{3}} \tag{10}$$

- Determination of Bus Bar Current on the Network

Bus-bar is simply a solid conductor which connects the feeders, incomers and other circuits. Bus bar are normally made of copper or aluminum, the current carrying capacity is the maximum current that the bus bar can carry before exceeding the maximum defined temperature rise normally 70^{o}c, the maximum required current capacity of all of the sources, connected to the bus bar including transformers/overhead lines/cables. (3.2) was used in determining the Bus bar current on each Bus on the network.

- Determination of Cable Size on the Network

Equation (11) was used in determining the cable size on the network, the transformer current values was divide by the multiplying factor of the cable.

Cable Size capacity $C_S = \frac{T_C}{C_{mf}}$ (11)

Where, C_S represent the cable size, T_C represent the transformer current capacity and C_{mf} represent Cable Multiplying factor

- Determination of Conductor Resistance on the Network

Equation (12) was used in determining the resistance value on each of the Buses on the network, we have,

$R = \frac{V}{I}$

(12)

- Determination of Conductor Cross Sectional Area on the Network

Equation (13) was used in determining the cross sectional area of the conductor, we have

$R = \rho \frac{l}{A}\ \Omega/\text{km}$ (13)

where: ρ is the resistivity of the material of the conductor; l is its length in meters and A is the area of the cross-section of the material.

$A = \rho \frac{l}{R}$ (14)

- Determining the Voltage Drop along Each Buses

Equation (15) was used in determining the voltage drop in the conductor, we have

voltage drop

$V_d = \frac{\left(\sqrt{3} \times I_B \times (R \cos 0.8 + j \sin 0.6) \times Cable\ length \times 1.5\right)}{(Line\ Voltage \times \text{No of run} \cdot 1000)}$

(15)

- Determining Resistance of Line per Kilometre

Table 1: The resistivity of different materials [14]

Material	ρ (Ω·m) at 20°C
Hard-drawn copper	1.77×10^{-8}
Aluminum	2.83×10^{-8}

Equation (13) was used in determining the resistance of line per Kilometre value of the route length of 58.6km connecting Bonny Island to the national grid using the of 132KV Aluminium conductor steel reinforced (ACSR) resistivity value in table 1. Converting to metre, we have L = 58.6×10^3m, with cross-sectional area of 8.24×10^{-15} Ω·m since the main emphasis was on Bus 5, Bus 6 and Bus 7.

- Reactance of Line per Kilometre

$X_o = 0.1445 log_{10} \frac{D_{GMD}}{r} + \frac{0.0157}{n} \Omega/\text{km}$ (15)

Where n=3 (number of phases on the line)

Note that,

$D_{GMD} = 1.26$D, and the value of $D = 880$mm, $D = 0.88$m (horizontal space)

Since $D_{GMD} = 1.26$D, hence the value of D above was used to determine the geometric mean distance of conductor, has shown below

$D_{GMD} = 1.26$D, then $D_{GMD} = 1.26 \times 0.88 = 1.108$m

Hence, $D_{GMD} = 1.108$m

$GMD = \sqrt[3]{D_{aa} \times D_{ab} \times D_{ac}} = 1.26D$ (16)

$r = \sqrt{\frac{A}{\pi}}$ (17)

Where: A, represent the conductor cross sectional area of the aluminum conductor steel reinforced with galvanized, (A = 182mm2ACSR/GZ). GMD, represent the geometric mean distance of conductor in m. r represent the radius of conductor in metre (m). While D is the distance between adjacent conductor (D=0.88m).

Recollect that:

Aluminum conductor steel reinforced (ACSR) of 132KV with cross-sectional area of A = 8.24×10^{-15}mm^2

Using equation (17) in determining the radius of the conductor, we have

$$r = \sqrt{\frac{A}{\pi}}$$

- Calculation of Per Kilometre Inductive Reactance X,

$$X_o = 0.1445\, log_{10}\frac{1.108}{7 \times 10^{-8}} + \frac{0.0157}{n}\,\Omega/\text{km}$$

- Impedance of Line Per Kilometre

$$Z_o = R_o + JX_o \qquad (18)$$

- Admittance of Line Per Kilometre

$$Y_o = G_o + JB_o \qquad (19)$$

Where; G_o represent the conductance of the line in Siemens while B_o is the susceptance of the line in Siemens.

Equation (20) below was used in calculating the per kilometre capacitive susceptance B, we have

$$B = \frac{7.5}{log_{10}\left(\frac{D_{GMD}}{r}\right)} \times 10^{-6}\Omega/\text{km} \qquad (20)$$

Using equation (14) above to determine the admittance (Y_o) of the network, we have

$$Y_o = G_o + JB_o$$

The HVAC transmission line has a series inductance *L*, shunt capacitance *C* per unit of length, operating voltage *V* and current I. The reactive power produced by the line was presented as follows

$$Q_c = \omega C V^2 \qquad (21)$$

and consumer's reactive power

$$Q_c = \omega L I^2 \qquad (22)$$

per unit length. If $Q_C = Q_L$

$$\frac{V}{I} = \left(\frac{L}{C}\right)^{1/2} = Z_s \qquad (23)$$

where Z_s is surge impedance of the line.

The power in the line (P_n) is called natural load. The power carried by the line depends on the operating voltage and the surge impedance of the line. Table 2 shows the typical values of a three phase overhead lines [15].

$$Z = VI = \frac{V^2}{Z_s} \qquad (24)$$

Table 2: Voltage Rating and Power Capacity

S/No.	Voltage (kV)	Natural load (MW)
1	330	168
2	132	150
3	33	95

The power flow in an AC system and the power transfer in a transmission line can be expressed

$$P = \frac{E_1 E_2}{X}\sin\delta \qquad (25)$$

Where E_1 and E_2 are the two terminal voltages, δ is the phase difference of these voltages, and X is the series reactance. Maximum power transfer occurs at δ= 90º and is

$$P_{max} = \frac{E_1 E_2}{X} \qquad (26)$$

Where P_{max} is the steady-state stability limit.

- The Presentation of HVAC Optimal Power Flow Connectivity of Bonny Island to the National Grid

The result in Figure 2, shows the HVAC optimal power flow connectivity of Bonny Island to the national grid.

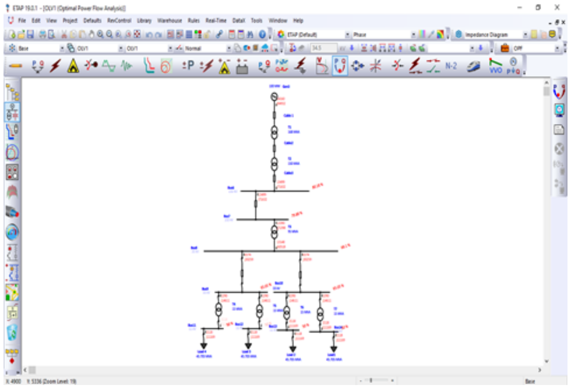

Figure 2: The HVAC Optimal Power Flow of Bonny Island to the National Grid

The result indicates that Bus 1 and bus 2 has the same Nominal voltage of 11KV, while there operating Bus percentage voltage was 94.711V and 94.373V respectively, which indicate that 0.338V loss was on the line. Bus 3 and Bus 4 has the same nominal voltage of 330KV, while it has the same operating Bus percentage voltages of 87.68V showing no voltage loss on the line. Bus 5, Bus 6 and Bus 7 has the same nominal voltage of 132KV, while there operating Bus percentage voltages were 80.198V, 80.179V and 79.878V respectively, indicating that the transmission voltage loss of 0.019V between Bus5 and Bus6, and 0.301V losses between Bus6 and Bus7. The Nominal voltage on Bus 8, Bus 9 and Bus 10 were rated at 33kv, with the same operating Bus percentage voltages on Bus9 and Bus10 (68.099V and 65.048V) respectively, indicating that the transmission voltage loss of 3.051V between Bus8 and Bus9, while there were no losses between Bus9 and Bus10. The 11kv nominal voltage was rated on Bus 11, Bus 12, Bus 13 and Bus 14 respectively, with the same operating Bus percentage voltages of 50%v respectively. The nominal Bus percentage voltage were 100% on all the Buses on the network.

The result indicates that Bus 1 and bus 2 has the same Nominal voltage of 11kv, while there operating Bus Kilo-voltages was 10.418kv and 10.381kv respectively, which indicate that 0.037kv losses was between Bus1 and Bus2 on the network. Bus 3 and Bus 4 has the same Nominal voltage of 330Kv, with the different operating Bus Kilo-voltages of 289.346kv and 289.344kv respectively, which indicate that 0.002kv losses was between Bus1 and Bus2 on the network. Bus 5, Bus 6 and Bus 7 has the same Nominal voltage of 132Kv, while there operating Bus Kilo-voltages were 105.862kv, 105.837kv and 105.439kv respectively, indicating that the transmission voltage has some minor losses of 0.025kv between Bus5 and Bus6, and 0.398kv losses between Bus6 and Bus7. The Nominal voltage on Bus 8, Bus 9 and Bus 10 were rated at 33kv, with the same operating Bus Kilo-voltages on Bus9 and Bus10 (22.473kv and 21.466kv) respectively, indicating that the transmission voltage has some minor losses of 1.007kv between Bus8 and Bus9, while there were no losses between Bus9 and Bus10. The 11kv nominal voltage was rated on Bus 11, Bus 12, Bus 13 and Bus 14 respectively, with the same operating Bus Kilo-voltages of 5.5kv respectively.

The result indicates that Bus 1 and bus 2 have the same Nominal voltage of 11kv, while there operating Bus angle was 0 and 0.2 respectively. Bus 3 and Bus 4 have the same Nominal voltage of 330kv and the same operating Bus angle of -0.4 respectively. Bus 5, Bus 6 and Bus 7 have the same nominal voltage of 132Kv, Bus5 and Bus6 have the same operating Bus angle 0f -1.2 respectively, while Bus7 have the operating Bus of -1.1. The nominal voltage in Bus 8, Bus 9 and Bus 10 were rated at 33kv respectively, with Bus8 having the operating Bus angle of -2.8, while Bus9 and Bus10 have the same operating Bus angle of 0.6 respectively. The nominal voltage of Bus 11, Bus 12, Bus 13 and Bus 14 was rated at 11kv respectively, with the same operating Bus angle of -1.2 respectively. The initial Bus angle on Buses were all zero (0).

The result indicate that the HVAC input load value was 2.118MW and the HVAC output load value was 2.29 MW on Bus 11, 12, 13 and 14 respectively.

In conclusion, the synchronous generator/power grid was rated at 100MW, 117.647MVA, 94.88%voltage, the operating Megawatt was 13.993MW with reactive power of 85.56Mvar, it has 100% Bus nominal voltage with 85%PF and 95% efficient. The 168MVA transformer was used as step-up from 11kv to 330kv and was stepped down to 132kv with 150MVA transformer and was transmitted to through Bodo in Gokhana Local Government Area to Bonny Island, was stepdown to 33kv with 95MVA transformer and was latter stepdown to 11kv with 15MVA transformers, the 11kv line connected to the 45.705MVA static load with the active, reactive, current and percentage rated values of (7.999MW, 45Mvar, 2399Amps and 17.5%PF). The designed loading of the four static load rating was 100%. The load was 7.917MW, 44.543Mvar and the feeder loss was 0.555MW and 0.133Mvar which was 100% normal, respectively.

In conclusion the total generation was 13.993MW, 85.565Mvar, 86.702MVA and 16.14% PF Lagging. While the total loading and demand was 7.999MW, 44.977Mvar, 45.682MVA and 17.51 %PF Lagging.

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