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# ANALYSIS AND SIMULATION OF HIGH VOLTAGE DIRECT CURRENT TRANSMISSION LINK BETWEEN BODO AND BONNY ISLAND

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## *ABSTRACT*

*The analysis and simulation of high voltage direct current transmission link between Bodo and Bonny Island, Rivers State, Nigeria, were achieved by obtaining the route length of the network using GPS, determining the Bus bar current, the cable size, the conductor cross sectional area, conductor resistance, the voltage drop on Bus 6 and Bus 7, and the resistance of line per Kilometre were also determined. Voltage stability technique was used in the implementation of the network. Electrical transient analyzer program (ETAP 19.0.1) simulation software was used in designing the network. In conclusion, The Bipolar HVDC link between Bus6 and Bus7 indicate that 132kv line with 50Hz was used as the rectifier input, while 132kv was used in connecting the primary and the secondary side of the rectifier transformer, the 150MVA transformer has 5% tap, same configuration was used for the inverter input and the inverter transformer. It will serve as a milestone to the Niger Delta and a catalyst for the continued success of its economic development, if incorporated into the ongoing Julius-Berger project along Bodo-Bonny Road in Rivers State, Nigeria.*

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

## INTRODUCTION

HVDC lines have typically been used to transfer large amounts of power over a long distance. According to (Oyedepo, Babalola, Nwanya, Kilanko, Leramo, Aworinde, Adekeye, Oyebanji, Abidakun & Agberegha, (2018), if properly configured, HVDC transmission could help mismatch and mitigate operational issues with HVAC transmission. In the perspective of Fadaeenejad, Shamsipour, Rokni and Gomes (2014), the challenges associated with increased penetration of HVAC transmission may be mitigated using a variety of other technologies or practices which include smart grid technologies, energy storage, or other flexible generating technologies. HVDC link is recently utilized for transmission lines longer than 50 km, it is usually utilized to interconnect two asynchronous grids with the same or different frequencies while avoiding stability disturbances (Sowilam, Kawady, & Shalwala, 2016). Bonny Island is one of the most industrialized communities that lies in the southernmost edge of West Africa in Nigeria and in close proximity to the city of Port Harcourt in Rivers State, hosting the country's largest oil and gas industries, its location is perfect for trade ships and vessels from the international and inland waters. This Island is not connected to the national grid but is being powered with four (4) gas turbines of 10MW each to generate power. This research aimed at analyzing and simulating the high voltage direct current transmission link between Bodo and Bonny Island, Rivers State, Nigeria. Necessary data about theroute length of the network was obtained using GPS, the Bus bar current, the cable size, the conductor cross sectional area, conductor resistance, the voltage drop on Bus 5, Bus 6 and Bus 7, and the resistance of line per Kilometre were 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.

### ii High Voltage Direct Current Transmission Line in Nigeria

The transmission of HVDC/HVAC Lines are being studied and utilized, since they are technically and economically feasible for transmission of bulk power system which ensure stability and efficient in transmission of long distances line (Guangfu *et al.*, 2012). According to Falcao, (2010), HVDC/HVAC is a new technology applied to transmission and distribution systems due to development in power electronics, this system takes the DC generated power, transmit then at transmission end its convert from DC to AC at the receiving end, these systems also provide Asynchronous connection and control of power through the link. In the perspective of Yu *et al.*, (2012), HVDC/HVAC are already established system to improve the stability of power system by controlling HVDC power flow through same AC transmission lines. In the view of (Gandoman *et al.*, 2018), HVDC transmission systems are beneficial for bulk power transmission from any location either off-shore or on-shore. According to Po1van, (2013) the HVDC interconnection between the existing HVAC asynchronous systems, shows that the integration HVDC need power control mechanisms and insulation was the main issues in HVDC. Currently, power control between receiving and transferring point of a HVDC/HVACis required for self-commutation, dynamic voltage control, power sharing between weak AC system and high load centers, in connecting urban areas and DC segmented grid (Larruskain *et al.*, 2014). Practically, interconnected HVDC/HVAC system makes power flow reliable since Power losses and investment loss is minimized, this technology also has multi-terminal interconnection ability which is utilized for long distance power transmission (Kamran, 2018). according to (Yang *et al.*, 2017), the operation of conversion of AC lines into DC lines can be considered as a solution to the existing electricity transmission and distribution bottlenecks worldwide, this conversion will provide stability, control facility and will lead to formulation of HVDC super grid in combining numerous renewable sources.

## HVDC Links Types

Various types of HVDC links are used in connecting two networks or system, which are classified into three types:

(i) Monopolar link: It has a single conductor of negative polarity and uses earth or sea for the return path of current. Sometimes the metallic return is also used. In the Monopolar link, two converters are placed at the end of each pole. Earthling of poles is done by earth electrodes placed about 15 to 55 km away from the respective terminal stations. But this link has several disadvantages because it uses earth as a return path. The monopolar link is not much in use nowadays.

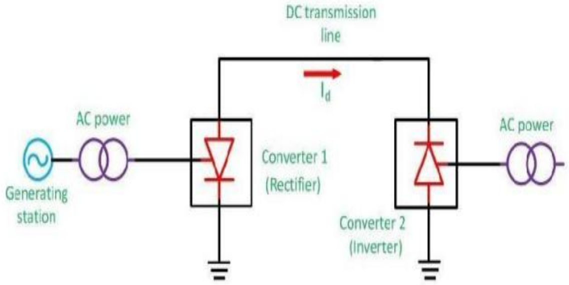


**Figure 1: Monopolar DC link (**Sridhar, 2019**)**

(ii) Bipolar link: The Bipolar link has two conductors one is positive, and the other one is negative to the earth. The link has converter station at each end. The midpoints of the converter stations are earthed through electrodes. The voltage of the earthed electrodes is just half the voltage of the conductor used for transmission the HVDC. The most significant advantage of the bipolar link is that if any of their links stop operating, the link is converted into Monopolar mode because of the ground return system. The half of the system continues supplies the power. Such types of links are commonly used in the HVDC systems.

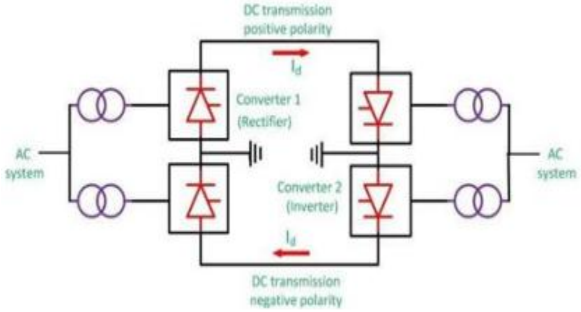


**Figure 2: Bipolar DC link (**Sridhar, 2019**)**

(iii) Homopolarlink: It has two conductors of the same polarity usually negative polarity, and always operates with earth or metallic return. In the homopolar link, poles are operated in parallel, which reduces the insulation cost. The homopolar system is not used presently.

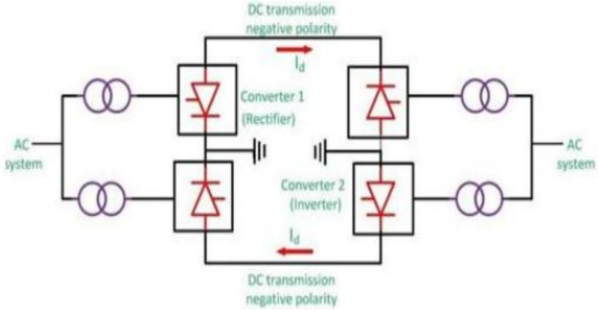


**Figure 3: Homopolar Link (**Sridhar**, 2019)**.

### HVDC Transmission Stations in Different Continent in the World

The HVDC transmission stations in differentcontinent in the world from 2010 to 2021 was shown in table 2.1 to 2.7 in appendix 1, with the name of the place, power rating of the station in megawatt (NW), the line voltage of the network, the total length of cable/pole in km used, the size of the rectifier station, the size of the converter station, and the type of HVDC link. The number HVDC transmission stations in DifferentContinent in the World are as follows:

i. Africa has two (2) HVDC Transmission Stations
ii. Australia and Oceania have two (2) HVDC Transmission Stations from 2010 to 2021
iii. Asia has forty-four (44) HVDC Transmission Stations from 2010 to 2021
iv. Europe has fifty-four (54) HVDC Transmission Stations from 2010 to 2021
v. North America has thirteen (13) HVDC Transmission Stations from 2010 to 2021
vi. South Americahas three (3) HVDC Transmission Stations from 2010 to 2021

## iii MATERIALS AND METHODS

The integration of Bonny Island to the national grid was designed with synchronous generator, power transformers, line voltage, Bus-Bar, Lump load, HVAC/HVDC transmission link which comprises of rectifier (converting AC to DC) and inverter (converting DC to AC) and GPS were used to determine 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 on the network. Electrical Transient Analyzer Program (ETAP) simulation software was used to achieve the designed network.

### Design Parameters for the Integration of Bonny Island to the National Grid

The HVAC/HVDC single line network design before optimization were shown in Figure 1, its emphasis was on Bus 5, Bus 6 and Bus 7.

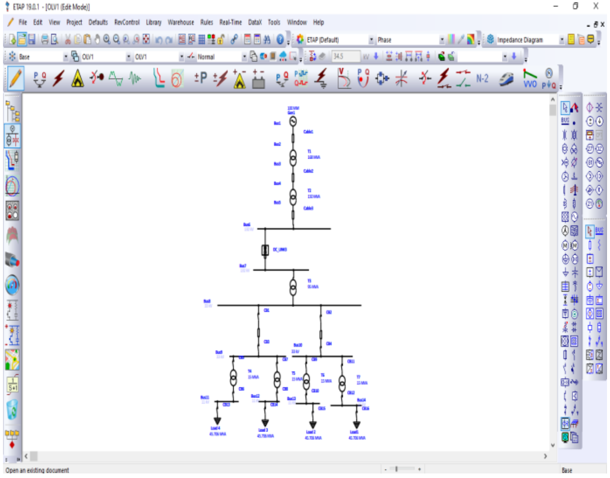


**Figure 4: The Bodo-Bonny Island HVDC Link.**

### Determination of Bus Bar Current on the Network

Equation (1) was used in determining the Bus bar current on each Bus on the network, we have

$$\text{Current } I = \frac{P(MVA)}{\sqrt{3}IV_L} \qquad (1)$$

### Determination of Cable Size on the Network

Equation (2) was used in determining the cable size on the network, the transformer current values was divided by the multiplying factor of the cable.

Cable Size capacity $\boldsymbol{C_S} = \frac{\boldsymbol{T_C}}{\boldsymbol{C_{mf}}}$ (2)

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

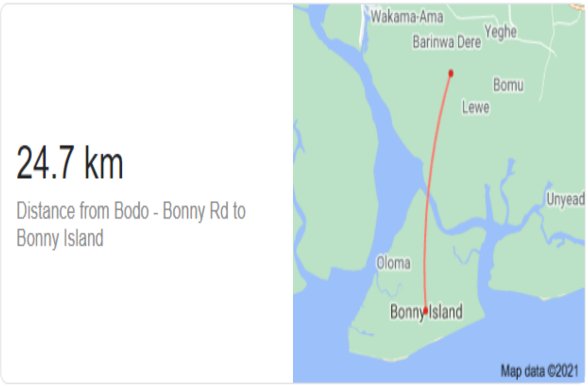
### Determination of Conductor Resistance on the Network

Equation (3) was used in determining the resistance value on each of the Buses on the network, we have,

$$R = \frac{V}{I} \quad (3)$$

### Determination of Conductor Cross Sectional Area on the Network

The bulk power transferred design will take 39 km long, Afa Creek will take about 530 m length and Nanabie Creek Bridge will take about 640 m length, the major river bridge will take about 750 m length over the Opobo Channel (Julius, 2012).



24.7 km

Distance from Bodo - Bonny Rd to Bonny Island

**Figure 5: 24.7 KM Distance from Bodo-Bonny Road to Bonny Island (**Google Map, 2021**)**

Equation (4) was used in determining the cross sectional area of the conductor, we have

$$R = \rho \frac{l}{A}\ \Omega/\text{km} \quad (4)$$

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.

$$A = \rho \frac{l}{R} \quad (5)$$

### Determining the Voltage Drop along Each Buses

Equation (6) was used in determining the voltage drop in the conductor, we have voltage drop

$$V_d = \frac{(\sqrt{3} \times I_B \times (R \cos 0.8 + j \sin 0.6) \times Cable\ \ length \times 1.5)}{(Line\ \ Voltage\ \ \times \text{No of run} \cdot 1000)} (6)$$

### Determining Resistance of Line per Kilometre

Equation (4) 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 of$2.83 \times 10^{-8}$ (Hemchandra, 2019). Converting to metre, we have L = $58.6 \times 10^{3}$m, with cross-sectional area of $8.24 \times 10^{-15}$ Ω·msince the main emphasis was on Bus 5, Bus 6 and Bus 7

**Reactance of Line per Kilometre**

$$X_o = 0.1445 log_{10} \frac{D_{GMD}}{r} + \frac{0.0157}{n} \Omega/\text{km} \qquad (7)$$

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

$$GMD = \sqrt[3]{D_{aa} \times D_{ab} \times D_{ac}} = 1.26D \qquad (8)$$

$$r = \sqrt{\frac{A}{\pi}} \qquad (9)$$

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:

**Calculation of Per Kilometre Inductive Reactance X,**

$$X_o = 0.1445\ log_{10} \frac{1.108}{7\times10^{-8}} + \frac{0.0157}{n} \Omega/\text{km} \qquad (10)$$

**Impedance of Line PerKilometre**

$$Z_o = R_o + JX_o \qquad (11)$$

**Admittance of Line PerKilometre**

$$Y_o = G_o + JB_o \qquad (12)$$

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

Equation (13) below was used in calculating the per kilometre capacitive susceptance B, we have

$$B = \frac{7.5}{log_{10}\left(\frac{D_{GMD}}{r}\right)} \times 10^{-6} \Omega/\text{km} \qquad (13)$$

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

$$Q_c = \omega C V^2 \qquad (14)$$

and consumer's reactive power

$$Q_c = \omega L I^2 \qquad (15)$$

per unit length. If $Q_C = Q_L$

$$\frac{V}{I} = \left(\frac{L}{C}\right)^{1/2} = Z_s \qquad (16)$$

Where $Z_s$ is surge impedance of the line.

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

$$P = \frac{E_1 E_2}{X} \sin \delta \qquad (17)$$

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.

$$P_{max} = \frac{E_1 E_2}{X} \qquad (18)$$

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

**Determination of Rectifier Capacity on the HVDC Link.**

Calculating the AC input current of the rectifier

$$R_{IP} = I_L \times V_{DC} \qquad (19)$$

Where; $R_{IP}$ is the AC input power of the rectifier, $I_L$ is the line current and $V_{DC}$ is the rectifier DC voltage value

Converting to MVA, we have

$$R_{IP} = \frac{I_L \times V_{DC}}{1000000} \text{ KVA} \qquad (20)$$

Converting (20) to Kilowatt, we have

$$R_{KW} = R_{IP} \times P_F \text{ KW} \qquad (21)$$

Determining the full power of the Rectifier

$$R_P = \sqrt{3} * V_L * I_L * \cos\theta \text{ Watt} \qquad (22)$$

Inputting the determine value in (22) into (23) to get Kilowatt, we have

$$R_P = \frac{\sqrt{3} * V_L * I_L * \cos\theta}{1000} \quad \text{KW} \qquad (23)$$

Determining the Output Power of the Rectifier

$$R_{OP} = V_{DC} \times I_{DC_{OP}} \cos\theta \qquad (24)$$

Where; $R_{OP}$ is the DC output power of the rectifier, $I_{DC_{OP}}$ is the DC line current of the rectifier and $V_{DC}$ is the rectifier DC voltage value.

Using the DC line current of the rectifier has the subject of the formula, we have

$$I_{DC_{OP}} = \frac{R_{OP}}{V_{DC} \times \cos\theta} \text{ A}_{\text{DC}} \qquad (25)$$

Inputting the determine value in (23) and (24) was inputted into (26) to get the Rectifier output DC current.

Calculating the output power of the Rectifier, we have

$$AC_{PR} = \frac{DC_{PR}}{Eff} \qquad (26)$$

Where; $AC_{PR}$ is the rectifier output power (AC),$DC_{PR}$ is the rectifier input power (DC) and $Eff$ is the efficiency of the rectifier.

Note that:

For us to determine the %loading of the rectifier will need to do some conversion, which are as follows.

Horse power (Hp)

$$H_P = K_w \times 746W \qquad (27)$$

Kilowatt power

$$KW_{pwr} = \sqrt{3}V_{FLC}I_{FLC} \times \cos\theta \times E_{ff} = DC_{pwr} \qquad (28)$$

$$KW_{pwr} = DC_{pwr} \qquad (29)$$

That means,

$$\sqrt{3}V_{FLC}I_{FLC} \times \cos\theta \times E_{ff} = \sqrt{3}V_{DC}I_{DC} \times \cos\theta$$

Hence,
For the %loading of the rectifier will have

$$E_{ff} = \frac{\sqrt{3}V_{DC}I_{DC} \times \cos\theta}{\sqrt{3}V_{FLC}I_{FLC} \times \cos\theta} \qquad (30)$$

$$E_{ff} = \frac{\sqrt{3}V_{DC}I_{DC}}{\sqrt{3}V_{FLC}I_{FLC}} \qquad (31)$$

**Determination of inverter Capacity on the HVDC Link**

Note that, the output of the DC current value in the rectifier was equal to the input current value in the inverter, has shown in (32).

$$I_{DC_{OP}} = \frac{R_{OP}}{V_{DC} \times \cos\theta} \mathrm{A_{DC}} \qquad (32)$$

Where, $I_{DC_{OP}}$ is the Rectifier output DC current and $I_{DC_{IIP}}$ is the Inverter input DC current

Calculating the inverter output current (AC), we have

$$A_{PO_{Inv}} = \frac{R_{OP}}{V_{DC}Eff} \text{ Amp} \qquad (33)$$

The value of the rectifier output power $R_{OP}$ in (24) and the efficiency value in (31) was inputted into (33) to determine the output power of the inverter.

The %loading of the rectifier
The value of the rectifier output power in (26) and the value of the inverter output power in (33) was inputted into (34) in determining the efficiency of the inverter, we have

$$A_{pwr} = \frac{DC_{pwr}}{EFF} \times 100 \qquad (34)$$

## RESULTS AND DISCUSSION

The Bipolar HVDC link between Bus6 and Bus7 in figure 6, shows that 132kv line with 50Hz was used as the rectifier input, while 132kv was used in connecting the primary and the secondary sides of the rectifier transformer, the 150MVA transformer has 5% tap, same configuration was used for the inverter input and the inverter transformer, as shown in figure 7.

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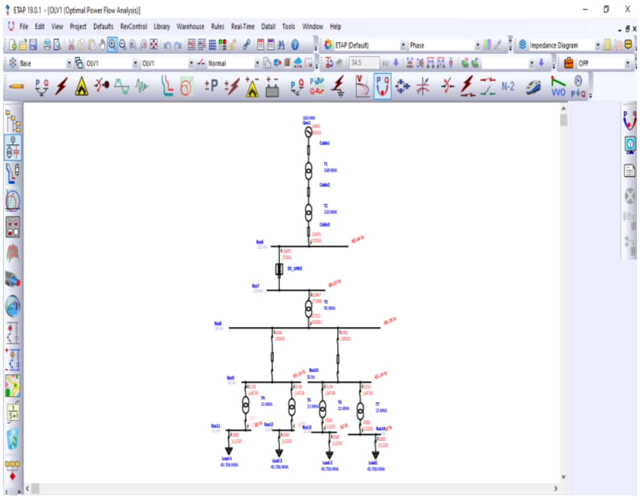
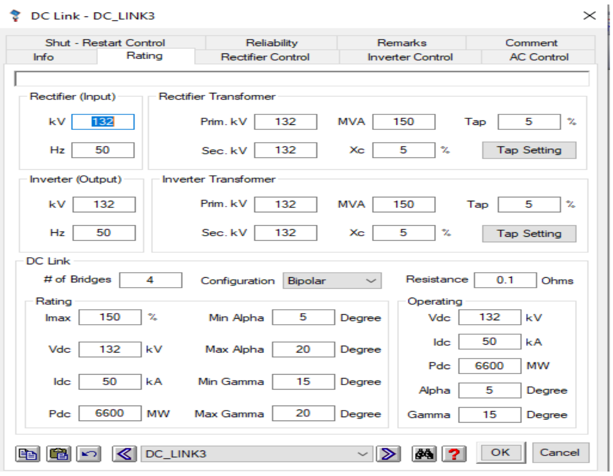


**Figure 6: TheHVAC/HVDC Optimal Power Flow of Bonny Island to the National Grid**



Rectifier (Input)
kV 132
Hz 50

Rectifier Transformer
Prim. kV 132
MVA 150
Tap 5 %
Sec. kV 132
Xc 5 %

Inverter (Output)
kV 132
Hz 50

Inverter Transformer
Prim. kV 132
MVA 150
Tap 5 %
Sec. kV 132
Xc 5 %

DC Link
# of Bridges 4
Configuration Bipolar
Resistance 0.1 Ohms

Rating
Imax 150 %
Vdc 132 kV
Idc 50 kA
Pdc 6600 MW
Min Alpha 5 Degree
Max Alpha 20 Degree
Min Gamma 15 Degree
Max Gamma 20 Degree

Operating
Vdc 132 kV
Idc 50 kA
Pdc 6600 MW
Alpha 5 Degree
Gamma 15 Degree

DC_LINK3

**Figure 7: The HVDC Link Configuration Rating**

In conclusion, the Bipolar HVDC link between Bus6 and Bus7 indicate that 132kv line with 50Hz was used as the rectifier input, while 132kv was used in connecting the primary and the secondary sides of the rectifier transformer, the 150MVA transformer has 5% tap, same configuration was used for the inverter input and the inverter transformer. It will serve as a milestone to the Niger Delta and a catalyst for the continued success of its economic development, if incorporated into the ongoing Julius-Berger project along Bodo-Bonny Road in Rivers State, Nigeria.

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