The Electricity Security in Nigeria: Design and Analysis of 750-kV Mega Grid

Article *in* International Journal of Engineering Research and Technology · September 2020

DOI: 10.37624/IJERT/13.9.2020.2219-2229

4 authors, including:

Ademola Abdulkareem
Covenant University Ota Ogun State, Nigeria

Lambe Mutalub Adesina
Kwara State University

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 9 (2020), pp. 2219-2229

The Electricity Security in Nigeria: Design and Analysis of 750-kV Mega Grid

Ademola Abdulkareem[1], Victoria Oguntosin[2], Oluwatimileyin Dare[3] and Adesina Lambe Mutalub[4]

[1,2,3] *Electrical & Information Engineering, Covenant University, Ota, Ogun State, Nigeria.*
[4]*Electrical and Computer Engineering Department, College of Engineering and Technology, Kwara State University, Malete, Nigeria.*

Abstract

Nowadays, due to the ever-increasing global energy demand and the complex option for an individual to install renewable power generation at his/her residence, it has become imperative to operate power plants that deliver energy to transmission and distribution systems at a reduced power loss and at the same time maximize efficiency. Therefore, the need arises to construct cost effective high transmission lines considered at Extra High Voltage (EHV) levels. In this study, the mechanical structures and electrical line parameters of a 750-kV single-circuit 4 conductors per bundle based on existing standards were designed. These EHV levels are then analyzed and the results obtained are compared with the 330-kV lower voltage levels in order to extract the benefits. The implementation of the designed 750-kV grid in Nigeria transmission system results in a significant reduction in the systems' power losses in comparison to the existing 330-kV system.

Keywords: Mega grid, Security, transmission line, power loss,

I. INTRODUCTION

The importance of an efficient and reliable power generation system cannot be overemphasized. It is the key to better standard of living and economic development in any nation. The power system encompasses the conveying of electric power generated at the power generation stations to the final consumers. This electric power is transmitted to the point of consumption or load centers with the aid of transmission lines. Transmission network lines are very important in getting power to the consumers as most generation plants in a bid to be closer to the needed resources are often sited far from load centers. Transmission system usually deals with very high voltages such as 33-kV, 66-kV, 132-kV, 330-kV and 765-kV. At these voltages, powers are transmitted to the distribution systems directly from the generating stations. The Transmission system is a link between generation and distribution systems. The other aspect of the power system that employs power lines is the distribution system that ensures that the transmitted power reaches the end consumers. Distribution involves stepping down very high voltage to lower voltage levels and power is distributed for both domestic and industrial consumption. In the operation of these transmission lines, losses due to resistance of the conductor and other factors are bound to occur and these losses make the power system less efficient. These losses further reduce the already inadequate power thereby crippling the nation's industrial and economic growth.

Since system loss is a considerable cost to utilities, consumers and the host country, its evaluation and reduction have been a unique area of interest to researchers [1]. Over the years, several methods have been developed to reduce these losses to the barest minimum, the most effective so far being extra high voltage transmission. The current practice in developed countries such as United States of America, Canada, Japan, Venezuela, Korea, Brazil, India, and Russia is the construction of infrastructure capable of transmitting electric power at a very high voltage such as 765-kV or above [2].

In Nigeria, there is a huge deficit in terms of the power being generated by the nation. This is as a result of stagnant power generation and an ever-increasing power demand. This ever-rising demand is as a result of the country's huge population of about 200 million people which has a corresponding average annual growth rate of 2.5% [3]. The widening gap between demand and supply of power has led to the loss of many small and medium industries which have in turn led to a higher unemployment rate. Unfortunately, this deficit has been allowed to grow over the years due to uncoordinated investments in generation, transmission and distribution sectors and also due to the poor execution of power projects.

The lack of a proper maintenance culture [4], vandalism and the poor state of transmission staff have also been identified as challenges that plagued the transmission sector. In addition to the above challenges, the Nigerian power sector has low efficiency due to a large amount of losses which translate to a huge financial drain [5, 6]. For a country with such a large population and a meagre peak generation of 5,074.70 MW [7], the transmission losses should be at its barest minimum. At the average generation level, Power consumption per capita is 156 kWh [8] which is extremely low when compared with South Africa's 4,841.28 kWh per capita [9]. Ultra-high voltage transmission lines such as the 765-kV have proven to allow for effective power transmission with minimal losses.

Table 1. ACSR for EHV transmission lines

Code Name	Al	Steel	Overall diameter	Total Sectional Area	Approx. Weight	Nominal Breaking load	Resistance at 20°C	Current Rating
	No/mm	No/mm	Mm	mm^2	Kg/km	KN	Ohm/km	A
Elk	30/4.50	7/4.50	31.50	588.5	2196.0	198.30	0.06079	985
Camel	54/3.35	7/3.35	30.15	537.7	1801.0	147.10	0.06080	985
Moose	54/3.53	7/3.53	31.77	597.0	1999.0	163.30	0.0548	1030

This paper therefore aims at designing a 750-kV transmission grid for the Nigerian power system to ensure efficient transmission of the available power to the nation minimal losses and to also cater for future needs.

II. ELECTRICAL DESIGN OF TRANSMISSION LINE

II.I CHOICE OF CONDUCTOR

From the extensive study of the existing 765-kV transmission lines and other EHV systems in Brazil, USA and Canada [10], the popular choice of aluminum conductor is the Aluminum Conductor Steel Reinforced (ACSR). It comprises a stranded steel core which carries the mechanical load while layers of stranded aluminum serve as the actual conductors carrying the current. The main purpose of choosing the ACSR is to achieve a higher strength-to-weight ratio of the transmission line. Also, the stranding of the conductor offers more flexibility. The ACSR conductor specification for EHV transmission lines is as presented in Table 1.

The stated ACSR conductors are obtained from the British standard (BS-215) [11] system for conductors. From Table 1, it is observed that the camel conductor weighs less than both the moose and elk while the moose has the least resistance. However, in order to reduce losses in EHV transmission, the number of conductors per phase is often increased making the camel conductor more suitable because of its reduced weight. Therefore, elk and the moose conductor are not best suited for usage because of their excessive weight. The camel conductor having the lowest weight, and considerably high mechanical strength and a rating of 985 A is therefore selected.

II.II CURRENT RATING OF THE LINE

From the study of the existing 765-kV transmission lines, it is observed that the lines are designed to transfer a typical power of 4,000 MVA and even more, the appropriate line current is calculated using equation (1):

$$I = \frac{S}{V\sqrt{3}} \quad (1)$$

$$I = \frac{4{,}000 \times 10^6}{750{,}000 \times \sqrt{3}}$$

$$I = 3{,}079.20\ A$$

II.III THE USE OF BUNDLE CONDUCTORS

Due to the very high current rating of the transmission line, a system of 4 Camel conductors per phase is adopted amongst other systems such as 3, 5, 6 and 8 conductors per bundle. The 3-conductor system doesn't provide a wide enough loading margin as well as the uneven nature of the bundling whereas for a 4-conductor bundle system, the total ampacity of each phase is 3,940A which already provides a wide enough margin when compared to the line current ratings (3,079.20A).

II.IV INSULATOR DESIGN

From Ref. [12], it is inferred that glass, porcelain and composite are the three major materials used in insulator production, of which the most common practice is the use of porcelain insulators. For voltages above 33kV, the suspension type insulators are the most economical [13]. It should be highly emphasized however that the choice of the type of these insulators also depends on the level of pollution of the environment.

The standard design is an arrangement of 32-35 porcelain insulators [14]. Each unit of the porcelain insulators discs has a maximum voltage rating of 25kV. Therefore, the minimum number of units in a suspension string is calculated using equation (2):

$$n = \frac{V}{25} \quad (2)$$

where V is nominal voltage in kV.

These porcelain insulators generally have a creepage distance of 370mm and mechanical failure load and no-load deformation strength of 210 kN and 140 kN (67% of failure load) respectively.

The suspension insulators are to be attached to the cross arms of the towers depending on the type of tower and the Right of Way (ROW) requirement. There are two major configuration techniques: the "V" and the "I" strings. The I-string of insulator follows the conductor and sways like a pendulum in a strong side wind whereas the V-strings prevent conductor movement at towers. The V- strings are mostly used for high voltage transmission system. This is not only to restrict conductor movement but to reduce ROW requirement as the

Table 2. Insulator Specifications

Insulator String	Configuration	Number of Discs and Assembly
Suspension String	V-90°	2 x 35 x 210 kN Double suspension
Tension String	Quadruple	4 x 35 x 210 kN Quad suspension
Pilot String	I	1 x 35 x 140 kN Double suspension

swaying nature of the I-string leads to an increase in ROW. This study tends to use a minimum amount of ROW and therefore prefers the V-strings to the I- string.

Furthermore, different types of strings are used depending on the function of the tower. The suspension strings are used on tangent towers where there are straight runs and the Stress is due to weight of line and wind load. The tension strings are used wherever the transmission line changes direction while the pilot strings are used wherever the tower begins or ends and often employ an I-string. A right angle is designed in between the two sets of strings of the V-configuration. The insulator specification is as presented in Table 2.

II.V EARTH WIRE DESIGN

The choice of material for the ground wire falls between galvanized steel and aluminium conductor. From a study of the sag and tension tables of both ground wire types, it is observed that the galvanized steel wires produce the least sag for a 400m span [11]. The galvanized steel series generally weighs more and possesses higher resistance than the aluminium series. The choice of ground wire for this study like the choice of conductor tends towards weight reduction and therefore chooses from the aluminium series displayed in Table 3.

Overall, a total of two ground wires were installed along both ends of the top of the steel towers. A shield angle of 15^o or 20^o is adopted for the outer phases of the 750-kV line conductors while the middle phase shall fall below the circle drawn with two ground wire points as diameter.

II.VI LINE PARAMETERS

Line parameters are those properties of the transmission line that provide information about the state of the system. With line parameters, the losses, efficiency, the sending and receiving powers etc. can be determined. The line parameters are also used in simulations such as the load flow and contingency fault analysis.

II.VII LINE RESISTANCE

The resistance (RT) of the four-conductor bundle is calculated using equation (3):

$$R_T = \frac{\rho L}{A} \qquad (3)$$

$\rho =$ Resistivity of Aluminum;
$A =$ Cross sectional Area of Aluminum in the bundle; and
$L =$ Length of the line (1 km).
On substituting, we have (for one conductor)

$$R_T = \frac{2.8735 \times 10^{-8}\ \Omega m \times 1000m}{476.6 \times 10^{-6} m^2 \times 4}$$
$$R_T = 0.01507\ \Omega/\text{km}$$

II.VIII GEOMETRIC MEAN DISTANCE (GMD AND GEOMETRIC MEAN RADIUS (GMR)

In the evaluation of inductance of composite conductors, it is required to determine the Geometric Mean Distance (GMD) and the Geometric Mean Radius (GMR) of the parallel circuit as shown in Figure 1. Thus, the equivalent GMD and GMR are calculated using equations (4) and (5).

$$GMR = 1.091\ \sqrt[4]{r.d^3} \qquad (4)$$
$$GMR = 1.091\sqrt[4]{0.015075\ \times\ 0.646^3}$$
$$GMR = 0.2755\ m$$

$$GMD = \sqrt[3]{D_{AB} \times D_{BC} \times D_{AC}} \qquad (5)$$

$$GMD = \sqrt[3]{14 \times 14 \times 28}$$
$$GMD = 17.64\ m$$

From the Electric Power Research Institute (EPRI) standards [15], the phase spacing for a horizontal arrangement of 800-kV system of conductors is 14m while the bundle diameter for a four-bundle conductor arrangement is 64.6 cm. The radius of the camel conductor is 15.075mm.

where:
$r =$ Radius of the conductor;
$d =$ Bundle diameter; and
$D_{AB}, D_{BC}, D_{AC} =$ Distance between phase conductors.

II.IX LINE INDUCTANCE AND INDUCTIVE REACTANCE

The Line Inductance and Inductive Reactance are calculated using equations (6) and (7) respectively:

$$L = 2 \times 10^{-7} \ln \frac{GMD}{e^{-1/4} GMR} \qquad (6)$$
$$L = 2 \times 10^{-7} \ln \frac{17.64}{e^{-1/4} \times 0.2755} \times 1000m$$
$$L = 2 \times 10^{-7} \times \ln 82.2149$$
$$L = 0.8819\ mH/km$$

$$X_L = 2\pi f L \qquad (7)$$
$$X_L = 2\pi \times 50 \times 0.8819 \times 10^{-6}$$
$$X_L = 0.2771\ \Omega/km$$

II.X LINE CONDUCTANCE

This accounts for real power loss between conductors or between conductors and ground. In overhead lines, this power loss is due to leakage currents at insulators and the effects of corona. It is very often neglected because it is a small component of shunt admittance [16]. Therefore, line

Table 3. Aluminum ground wires

Description	Overall diameter	Nominal area	Approximate mass	Rated strength	Coefficient of linear expansion	Resistance at 20^{o}C
	Mm	mm^2	Kg/mm	Kgf	Per ^{o}C	Ohms
19/2.00	10.00	59.70	164	1790	23 x 106	0.552
7/3.81	11.43	79.81	218	2387	23 x 106	0.4125
19/2.46	12.30	90.31	248	2576	23 x 106	0.3663

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 13, Number 9 (2020), pp. 2219-2229

Conductance, $G = 0$

II.XI LINE CAPACITANCE AND SUSCEPTANCE

The Capacitance is calculated using equation (8):

$$C = \frac{2\pi\varepsilon_o}{\ln(GMD/GMR)} \quad (8)$$

$$C = \frac{2\pi \times 8.85 \times 10^{-12}}{\ln(17.64/0.2755)}$$
$$C = \frac{2 \times 3.142 \times 8.85 \times 10^{-12} \times 1000m}{4.1593}$$
$$C = 0.01337\ \mu F/km$$

The line Susceptance is calculated using equation (9):

$$B = 2\pi f C \quad (9)$$

$$B = 2 \times 3.142 \times 50 \times 0.01337\ \times 10^{-6}$$
$$B = 4.2 \times 10^{-6}\ Siemens/km$$

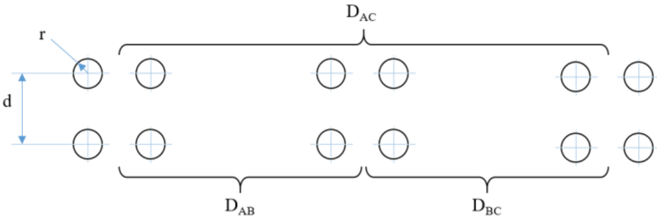

Fig. 1. Phase spacing and bundle spacing of conductors

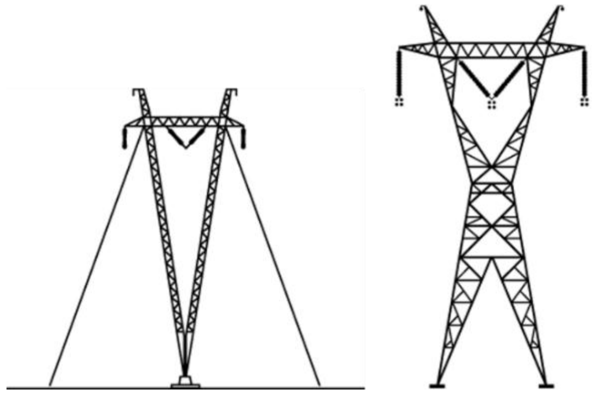

Fig. 2. Horizontal type towers

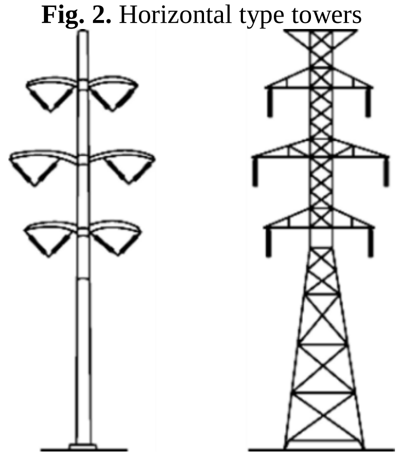

Fig. 3. Phase spacing and bundle spacing of conductors

III. MATH

Mechanical design of the transmission line involves the design of the support structures most especially the towers and determination of safe clearance levels. It involves the design of structures that do not come in contact directly with the flow of alternating current. The selection of basic tower configuration for an overhead transmission line is a function of several parameters such as the line voltage, number of circuits per tower and the conductor bundling. For EHV, care has to be taken to ensure that the tower is designed to reduce the environmental hazards that may arise from the electrical and magnetic fields, radio interference and audible noises. Depending on requirements for availability and necessary ROW, single, double or multiple circuits are erected. Single circuits are often preferred due to narrower ROW requirements. The mechanical design of towers involves the determination of the height, width, clearances level and ROW required for the transmission towers. It also involves specifying the type of material used, support structure and shape.

III.I MATERIAL FOR TOWER CONSTRUCTION

Several structures used in EHV transmission use materials such as Steel, Galvanized steel and Aluminum [12]. The structures are constructed of Galvanized steel because of its higher mechanical strength. Steel towers generally possess a longer life span and can thrive in extreme climatic conditions and allow for use of longer spans.

III.II SUPPORT STRUCTURE

As regards the support structure of the towers, a choice of self-supporting horizontal structures is preferred over the guyed towers. Although guyed tower consumes a lesser amount of steel and other construction materials, the self-supporting structures allow for use of lesser ROW as shown Figures 2 and 3.

III.III CONDUCTOR ARRANGEMENT

The conductor arrangement and the number of circuits also determine the type of tower that is chosen. The vertical type is generally often taller than the horizontal types. The horizontal shape of towers is adopted over the other common vertical shape type. This is because the vertical shape type is more economically suitable for a double-circuit system. The horizontal scheme also offers greater performance from the consideration of audible noise, radio interference and corona effect because more clearances can easily be obtained.

Table 4. Developed 750-kV Line parameters to replace the existing 330-kV transmission lines

BUS NAME		LENGTH	SERIES IMPEDANCE		SHUNT ADMITTANCE	
FROM	TO	km	R (p.u)	X (p.u)	G (p.u)	B/2 (p.u)
Akamgbe	Ikeja-West	17	0.0005	0.0084	0	0.0209
Ayede	Oshogbo	115	0.0031	0.0566	0	0.1413
Ikeja-West	Egbin	62	0.0017	0.0305	0	0.0762
Ikeja-West	Benin	280	0.0075	0.1379	0	0.3441
Oshogbo	Jebba	249	0.0067	0.1227	0	0.306
Jebba TS	Jebbs GS	8	0.0002	0.0039	0	0.0098
Jebba TS	Shiroro	244	0.0065	0.1202	0	0.2999
Jebba TS	Kainji	81	0.0022	0.0399	0	0.0995
Kainji	Kebbi	310	0.0083	0.1527	0	0.381
Shiroro	Kaduna	96	0.0026	0.0473	0	0.118
Jos	Gombe	265	0.0071	0.1305	0	0.3257
Benin	Sapele	50	0.0013	0.0246	0	0.0615
Benin	Onitsha	137	0.0037	0.0675	0	0.1684
Onitsha	New Heaven	96	0.0026	0.0473	0	0.118
Onitsha	Alaoji	138	0.0037	0.068	0	0.1696
Alaoji	Afam	25	0.0007	0.0123	0	0.0307
Sapele	Aladja	63	0.0017	0.031	0	0.0774
Delta	Aladja	30	0.0008	0.0148	0	0.0369
Kainji GS	Jebba GS	81	0.0022	0.0399	0	0.0995
Ayede	Ikeja-West	137	0.0037	0.0675	0	0.1684
Egbin TS	Aja	28	0.0007	0.0135	0	0.0338
Kaduna	Jos	197	0.0053	0.097	0	0.2421
Jos	Maiduguri	275	0.0074	0.1355	0	0.338
Oshogbo	Ikeja-West	252	0.0068	0.1241	0	0.3097
Benin	Delta	107	0.0029	0.0527	0	0.1315
Onitsha	Okpai	80	0.0021	0.0394	0	0.0983
Geregu	Ajaokuta	5	0.0001	0.0025	0	0.0061
Shiroro	Kaduna	96	0.0026	0.0473	0	0.118

The tower designations apply as follows:

1. Suspension towers for straight runs with angle of deviation of about 2^o - 5^o.
2. Several forms of tension towers (Type B, C, D and E) are used where the deviation angle exceeds 5^o but is less than 60^o.

Other types of towers to be employed are the transposition towers for line transposition and the special suspension towers for river crossings and valley crossings with spans of about 1000m.

III.IV TRANSMISSION CORRIDOR WIDTH AND ROW

A ROW is a large components part of transmission line and helps to give a well-spaced margin among high-voltage lines and surrounding structures. ROW is used as access inspection at the ground-based and also during routine checkup or for maintenance/repair sake. Adequate ROW must be maintained to avoid ground faults.

Transmission corridor widths may or may not be equal to the width of the ROW that should be selected because the latter are determined by local requirements or by special technical or economic constraints. ROW is determined based on the line design and local conditions to limit construction which would interfere with the line operation. Currently, the cutting of trees has been limited to the trees that would interfere with the operation of the line. In areas with thick vegetation, it is often arranged with the owners of the ROW for trees outside the ROW to be removed to remove the danger of trees outside the

Table 5. Load Flow Result of the 750-Kv Super Grid Simulation in MATLAB

Bus No	Voltage Mag.	Angle Degree	Load		Generation		Injected Mvar
			MW	Mvar	MW	Mvar	
1	0.937	6.238	114.500	85.900	0.000	0.000	0.000
2	1.050	30.841	7.000	5.200	624.700	128.832	0.000
3	1.030	23.635	0.000	0.000	495.000	183.406	0.000
4	1.030	23.612	11.000	8.200	0.000	0.000	0.000
5	0.916	3.022	201.200	150.900	0.000	0.000	0.000
6	0.859	-4.575	275.800	206.800	0.000	0.000	0.000
7	0.884	-3.022	0.000	0.000	154.800	0.000	0.000
8	0.894	-3.932	633.200	474.000	0.000	0.000	0.000
9	0.866	-5.448	244.700	258.500	0.000	0.000	0.000
10	1.050	0.000	68.900	51.700	738.421	845.696	0.000
11	1.034	-1.448	274.400	205.800	0.000	0.000	0.000
12	1.012	-14.872	290.100	145.000	0.000	0.000	0.000
13	0.950	0.029	0.000	0.000	100.600	0.000	0.000
14	0.971	-0.867	383.300	287.500	0.000	0.000	0.000
15	1.050	4.046	20.600	15.400	190.300	374.551	0.000
16	1.048	-10.632	13.800	10.300	0.000	0.000	0.000
17	1.050	9.849	0.000	0.000	670.000	192.500	0.000
18	1.042	7.379	96.500	72.400	0.000	0.000	0.000
19	0.934	13.078	184.600	138.400	0.000	0.000	0.000
20	1.050	30.128	0.000	0.000	750.000	367.842	0.000
21	0.855	7.292	177.000	133.400	0.000	0.000	0.000
22	0.997	10.740	427.000	320.200	0.000	0.000	0.000
23	1.050	13.121	52.500	39.400	431.000	470.351	0.000
24	1.050	-1.435	70.300	36.100	388.900	308.104	0.000
25	0.867	-16.511	220.600	142.900	0.000	0.000	0.000
26	0.991	-10.140	193.000	144.700	0.000	0.000	0.000
27	1.006	-16.800	70.300	52.700	0.000	0.000	0.000
28	1.036	-20.289	130.600	97.900	0.000	0.000	0.000
29	1.067	-17.691	52.500	39.400	0.000	0.000	0.000
30	1.043	-22.713	66.500	47.800	0.000	0.000	0.000
31	1.053	-21.947	61.440	44.210	0.000	0.000	0.000
32	1.042	-15.036	88.500	60.300	0.000	0.000	0.000
Total			4429.84	3275.01	4543.721	2871.283	0

Real power loss = 4543.721 - 4429.940 = 113.781 MW

ROW falling across the line. The transmission corridor width is therefore the distance measured from the ROW centerline where audible noise, radio interference and television interference fall within acceptable levels. The minimum signal to noise ratio should be 30. Also, the Audio noise level for 750-kV system should be less than 55 dB (A).. Most acceptable transmission corridor for 765kV reviewed fall within the 60-88 m range but in this study, 64m is adopted.

III.V THE TRANSMISSION TOWER

The choice of transmission tower is a horizontal, self-supporting galvanized steel tower. The tower is designed using the clearance levels and the EPRI [15] standards for 800-kV towers. The single circuit nature of the power system ensures that the horizontal type is chosen over the vertical types. The distance between conductors of each phase as used in the calculation of the GMD is 14m. This decision ensures that the width of the tower exceeds 28m i.e. the total distance between the conductors at the ends of the tower minimum. The height of the tower is also chosen to exceed the sum of the ground and the mid-span clearances as shown Figure 4.

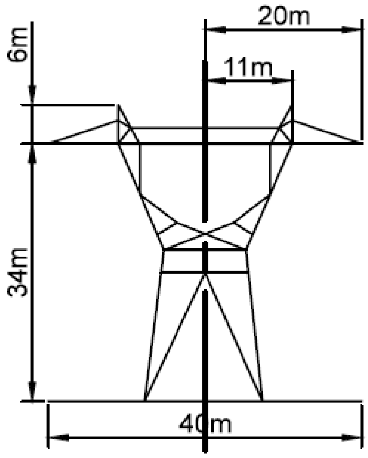

Fig. 4. Galvanized Steel towers for 750kV

III.VI CLEARANCES

Clearance levels adopted are as follows:

1. Ground clearance: In order for environmental criteria such as radio and television interference and audible noises to be met, the minimum height clearance according to the EPRI [15] for a 765kV is between 13.7 to 16.5m, while the lowest bundle height to earth at structure is 28 m.
2. Flood level clearance: the minimum Clearance above rivers and lakes is about 9.4m or at least 3.05m above maximum flood level.
3. Clearance and swing angles: for V-string with no swing angle, the stipulated clearance is 5m. The I-string, depending on the swing, has clearances varying from 1.3m to 5.1m
4. Rail track crossing: Where railroad tracks are parallel to or crossed by overhead lines, all portions of the supporting structures, support arms, anchor guys, and equipment attached thereto less than 6.7 m above the nearest track rail shall have horizontal clearances not less than the values[17].

Mid-span clearance: This is the distance between ground and the center of the span of the conductor and is given as 12.4 m [18].

III.VII CORONA LOSSES

The effects of corona are important especially for Extra High Voltage transmission lines. Corona discharge is formed when the electric field formed at the surface of the transmission line conductor becomes so large that it starts to breakdown the surrounding air (30kV/cm during fair weather) thereby producing ionization of the area close to the conductor. It can be detected due to its visible light in form of purple glow consisting of micro arcs and its sound can be heard through its hissing and cracking sound. The oscillatory nature of the discharge generates high frequency and short-current pulses which lead to significant power loss as well as interference with radio and television signals. The effect of the formation of corona is not limited to only losses in the transmission line but also audible noises and visible flashes.

The level of corona is greatly affected by the size of the conductor, spacing between conductors, the line voltage and the atmospheric conditions. Surface impurities such as water droplets cause field concentration which enhances corona discharge. Thus, during bad weather, corona discharge is more intense and losses are far greater. Rough surfaces are more liable to corona because the unevenness of the surface decreases the value of the breakdown voltage. The smelling of the presence of ozone production is noticed during corona activity. The effects of corona are cumulative and permanent and the failure can occur without warning [19].

III.VIII DISRUPTIVE CRITICAL VOLTAGE

This is the minimum phase to neutral voltage at which corona occurs. In order for corona to occur, the value of g must be equal to the breakdown strength of air g_o. The expression in equation (10) is under standard conditions: pressure at 76cmHg, temperature of 25ºC

The disruptive critical voltage of the transmission line is thus calculated as follows:

$$V_c = 21.2\, m_c.\delta.r \ln\frac{D}{r} \qquad (10)$$

where
Mc = surface irregularity factor, 0.90 for cables with more than 7 strands;
δ = air density factor = 1.0; and
D = distance between phase conductor in cm.

Therefore,

$$V_c = 21.2 \times 0.90 \times 1 \times 1.5075 \times \ln\frac{1400}{1.5075}$$
$$V_c = 196.56\ kV$$

III.IX VISUAL CORONA VOLTAGE

This is the minimum phase to neutral voltage at which visible flashes and glows begin to appear along the transmission line conductors.

The visual corona voltage is calculated using equation (11):

$$V_v = 21.2 m_V.\delta.r\left(1+\frac{0.3}{\sqrt{\delta r}}\right)\ln\frac{D}{r} \qquad (11)$$

where
Mv = surface irregularity factor = 0.83 for stranded wires

$$V_v = 21.2 \times 0.83 \times 1 \times 1.5075 \times \left(1+\frac{0.3}{\sqrt{1\times 1.5075}}\right)\ln\left(\frac{1400}{1.5075}\right)$$
$$V_v = 222.85\ kV$$

III.X POWER LOSSES DUE TO CORONA

The Power losses due to the formation of corona using the Peterson's formula is calculated using equation (12):

$$P_c = \frac{0.545}{\delta}(V - V_c)\sqrt{r/_{GMD}} \qquad (12)$$

where
$V =$ Voltage in-kV to neutral
$V_c =$ Disruptive critical voltage

$$P_c = \frac{0.545}{1} \times \left(\frac{750}{\sqrt{3}} - 196.56\right) \times \sqrt{\frac{1.5075}{1764}}$$

$$P_c = 3.767\ kW/km$$

IV. CALCULATION OF THE DIMENSIONS OF THE LINE PARAMETERS AND RESULTS ANALYSIS

This section employs the electrical and mechanical design methodology to calculate the dimension for the following line parameters: series impedance; shunt impedance; base impedance; and base admittance using equations (13), (14), (15) and (16) respectively. These values are then converted to their per unit values for simplicity. The results of surge impedance loading of the 750-kV transmission line and the calculated values of single circuit impedances and admittances are also obtained.

IV.I LINE PARAMETERS

For the 750-kV transmission line, the line parameters are calculated as follows:

Table 6: Load-flow result of the existing 330-kV network

From Bus	To Bus	Active Power flow (MW)	Reactive Power flow (Mvar)	Complex Power flow (MVA)	Active Power loss (MW)	Reactive Power loss (Mvar)
1	2	115.9879	-30.7254	119.9885	1.4879	-116.625
1	3	501.7121	-55.2062	504.7403	6.633	-11.5062
2	1	-114.5	-85.9	143.14	1.4879	-116.625
3	1	-495.079	43.7	497.0041	6.633	-11.5062
3	4	-494.329	-38.5246	495.8279	0.671	-2.3843
3	5	321.8366	13.46	322.1179	5.6016	-78.1002
3	23	656.5715	-26.8354	657.1197	26.6503	75.2551
4	3	495	36.1403	496.3176	0.671	-2.3843
5	3	-316.235	-91.5602	329.2231	5.6016	-78.1002
5	6	177.026	42.3656	182.0249	1.5765	-71.7504
5	8	128.921	11.3987	129.4239	1.0055	-93.4136
5	13	-190.912	-113.104	221.9008	3.238	-172.597
6	5	-175.45	-114.116	209.2965	1.5765	-71.7504
6	7	-80.9763	-36.6775	88.8954	0.1617	-34.9959
6	8	-19.3741	-56.0066	59.2629	0.0222	-98.1078
7	6	81.138	1.6816	81.1554	0.1617	-34.9959
7	8	73.662	-1.6816	73.6812	0.0577	-17.1578
8	5	-127.916	-104.812	165.3723	1.0055	-93.4136
8	6	19.3963	-42.1012	46.3544	0.0222	-98.1078
8	7	-73.6044	-15.4763	75.2138	0.0577	-17.1578
8	9	247.6955	235.7035	341.9199	2.9955	-22.7965
8	10	-403.892	-362.05	542.4106	6.4373	2.3304
8	12	-44.8346	-59.1121	74.1915	1.2761	-96.9254
8	13	-250.045	-126.151	280.0656	6.7175	-147.384
9	8	-244.7	-258.5	355.9499	2.9955	-22.7965
10	8	410.3295	364.3806	548.7654	6.4373	2.3304
10	11	276.706	169.1378	324.3051	2.306	-36.6622
10	13	-196.716	18.1493	197.5513	2.8778	-27.954
11	10	-274.4	-205.8	343	2.306	-36.6622
12	8	46.1107	-37.8133	59.6326	1.2761	-96.9254
12	13	54.4893	37.8133	66.3244	0.3626	-83.348
13	5	194.15	-59.4926	203.0606	3.238	-172.597
13	8	256.7627	-21.2328	257.6391	6.7175	-147.384
13	10	199.5937	-46.1033	204.8491	2.8778	-27.954
13	12	-54.1266	-121.161	132.7018	0.3626	-83.348
13	14	14.1681	-155.65	156.2934	0.3681	-165.95
13	15	-262.415	-26.9578	263.7962	1.1368	-36.8382
13	16	-473.901	20.0871	474.3261	4.7811	-12.9197
13	18	-257.532	123.0107	285.4022	4.4327	-70.3566
14	13	-13.8	-10.3	17.22	0.3681	-165.95

15	13	263.552	-9.8805	263.7372	1.1368	-36.8382
15	17	-93.852	3.7389	93.9265	0.2026	-50.8631
16	13	478.6817	-33.0068	479.8183	4.7811	-12.9197
16	17	191.3183	-28.4304	193.4192	0.7637	-46.2284
17	15	94.0547	-54.602	108.755	0.2026	-50.8631
17	16	-190.555	-17.798	191.384	0.7637	-46.2284
18	13	261.9648	-193.367	325.6017	4.4327	-70.3566
18	19	-703.819	82.449	708.6316	46.1812	14.2387
18	20	178.7979	112.9396	211.4806	1.7979	-20.4604
18	22	78.4561	-140.421	160.8525	7.0193	-97.1128
19	18	750	-68.2103	753.0954	46.1812	14.2387
20	18	-177	-133.4	221.6406	1.7979	-20.4604
21	22	378.5	359.6307	522.1077	22.9367	-3.8779
22	18	-71.4367	43.3086	83.5394	7.0193	-97.1128
22	21	-355.563	-363.509	508.4916	22.9367	-3.8779
23	3	-629.921	102.0904	638.1404	26.6503	75.2551
23	24	294.9635	64.7522	301.9873	4.8635	-80.2478
23	25	653.5577	486.4913	814.7463	21.1085	145.1124
24	23	-290.1	-145	324.3193	4.8635	-80.2478
25	23	-632.449	-341.379	718.7013	21.1085	145.1124
25	26	230.5674	155.9158	278.3362	9.9674	13.0158
25	27	208.8818	40.7631	212.8221	4.8743	-25.2542
26	25	-220.6	-142.9	262.8398	9.9674	13.0158
27	25	-204.008	-66.0173	214.4233	4.8743	-25.2542
Total					203.62	-1556.45

Series Impedance:

$$Z = R + jX \quad (13)$$

$$Z = 0.01507 + j0.2771\ \Omega/km$$

Shunt Admittance:

$$Y = G + jB \quad (14)$$

$$Y = 0 + j4.2 \times 10^{-6}\ S/km$$

IV.II LINE MODELLING

The determination of the line parameters is carried out using the per unit system, the base impedance is calculated using equation (15) while the base admittance is directly obtained using equation (16). Typical base value of 1,000 MVA is adopted for the 750-kV transmission grid system. That is

$$V_{base} = V_{line} = 750\ kV$$

$$Z_{base} = \frac{(V_{base})^2}{MVA_{base}} \quad (15)$$

$$Z_{base} = \frac{(750{,}000)^2}{1000 \times 10^6}$$

$$Z_{base} = 562.5\ \Omega$$

$$Y_{base} = \frac{1}{Z_{base}} \quad (16)$$

$$Y_{base} = \frac{1}{562.5}$$

$$Y_{base} = 1.709 \times 10^{-3}\ Siemens$$

IV.III COMPUTATION OF PER UNIT VALUES

Per unit system (which is the ratio of the actual value to the base) is calculated for resistance Rp.u, reactance Xp.u, and susseptance Bp.u using equations (17), (18) and (19) respectively as follows:

$$R_{p.u} = \frac{R_{actual\ value}}{Z_{base}} \quad (17)$$

$$R_{p.u} = \frac{0.01507}{562.5}$$

$$R_{p.u} = 0.00002679\ pu/km$$

$$X_{p.u} = \frac{X_{actual\ value}}{Z_{base}} \quad (18)$$

$$X_{p.u} = \frac{0.2771}{562.5}$$

$$X_{p.u} = 0.0004926\ pu/km$$

$$B_{p.u} = \frac{B_{actual\ value}}{Y_{base}} \quad (19)$$

$$B_{p.u} = \frac{4.2 \times 10^{-6}}{1.709 \times 10^{-3}}$$

$$B_{p.u} = 0.002458\ pu/km$$

Per Unit Series Impedance:
Per unit impedance is obtained using equation (20):

$$Z = R + jX \quad (20)$$

$$Z = 0.00002679 + j0.0004926\ pu/km$$

Per Unit Shunt Admittance:
Per unit shunt admittance is obtained using equation (21):

$$Y = G + jB \quad (21)$$

$$Y = 0 + j0.002458\ pu/km$$

IV.IV CALCULATION OF THE SURGE IMPEDANCE LOADING (SIL) OF THE 750-KV TRANSMISSION LINE

The surge impedance loading is defined as the load at which the reactive power absorbed by the inductance of the line is equal to the reactive power supplied by the capacitance of the line. It is the power delivered by a lossless line to a load resistance equal to the surge of characteristic impedance. SIL mainly depends on voltage class and the conductor configuration of the line. For the load equal to the SIL, the voltage of the line does not change along the length of the line hence no extra compensation for reactive power is required. This means that at SIL, the transmission line consumes as much reactive power as it generates and the terminal voltages are equal to each other. SIL, characteristic impedance and power of SIL are therefore calculated using equations (22), (23) and (24) respectively.

$$P_{SIL} = \frac{V^2}{Z_C} \tag{22}$$

$$Z_C = \sqrt{\frac{Z}{Y}} \tag{23}$$

$$Z_C = \sqrt{\frac{0.01507 + j0.2771}{4.2 \times 10^{-6}}}$$

$$Z_C = \sqrt{3588.1 + j65{,}976.2}$$

$$Z_C = \sqrt{66{,}073.7}$$

$$Z_C = 257.04\ \Omega$$

$$P_{SIL} = \frac{V^2}{Z_C} \tag{24}$$

$$P_{SIL} = \frac{750{,}000^2}{257.04}$$

$$P_{SIL} = 2{,}188.38\ MW$$

This implies that in order to maintain stability in the lines, the transmission capacity is limited to the Surge Impedance Loading (SIL) of 2,188.38 MW. This power transfer capability can be improved by increasing the SIL level. The SIL level can be increased by reduction in the transmission line inductance. This can be made possible by [20]:

1. Increasing bundle spacing;
2. Increase in diameter of conductor; and
3. Reduction in phase to phase spacing.

The calculated line parameters are then taken into account for the upgrade to be possible. The conductors are replaced with conductors with higher current capacity. Therefore, the 'Bersimis' two conductor bundle for the 330kV is upgraded to a four Camel conductor bundle based on the design. Therefore, the result of the line parameters for all the existing lines in the 330-kV transmission system is developed as a representation of 750-kV transmission system. Table 3 shows the developed line parameters for 750-kV transmission line.

In accordance with the developed 750-kV transmission line data of Table 4, a power-flow analysis was carried out and the result showed a 44.2% large reduction in the power losses when compared with the existing 330-kV transmission line. The real power losses in the 750-kV transmission line amounted to 113.781 MW while that of the existing 330-kV is 203.62 MW as shown in Tables 5 and 6 respectively.

V. CONCLUSIONS

The study successfully designed a 750-kV Super grid transmission line together with its major components: the conductors, insulators and the steel tower providing detailed specifications for each of the above. Transmission line data was successfully formulated to aid in various power system analyses and to also determine other transmission line properties. The study also showed that the implementation of a 750-kV grid in Nigeria results in a significant reduction in the systems' power losses. This is because a 44.2% Power loss reduction was confirmed upon comparing the 750-kV line losses with the 330-kV line losses.

The result of voltage analysis of the 750-kV also showed reasonable and appreciable values better than the existing 330-kV network. The implementation of the designed 750-kV grid is guaranteed to ensure a more stable power system with reduced losses and also eradicate the erratic nature of the present 330-kV transmission line in Nigeria. A stable power system in return ensures improved standard of living and a growing economy.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the management of Covenant University for her part sponsorship and support toward the success of this research work.

REFERENCES

[1] L. F. Ochoa, R. M. Ciric, A. Padilha-Feltrin, and G. P. Harrison, "Evaluation of distribution system losses due to load unbalance," in 15th PSCC, 2005, vol. 6, pp. 1-4.

[2] H. Huang, D. Kumar, V. Ramaswami, and D. Retzmann, "UHV 1200 kV AC Transmission," in Power Transmission and Distribution (GRIDTECH), 2007.

[3] W. Inc. (2019). World population. Available: www.worldometers.info/world-population/nigeria-population/

[4] C. O. Awosope, "Nigeria electricity industry: issues, challenges and solutions," Covenant University 38th Public Lecture, 2014

[5] A. Abdulkareem, C. Awosope, and A. Awelewa, "On The Cost Implications of Technical Energy Losses on Nigerian 330-kV Transmission Grid System," International Journal of Science and Research (IJSR), pp. 1289-1299, 2013.

[6] A. Abdulkareem, C. Awosope, A. Adoghe, and S. Alayande, "Investigating the Effect of Asymmetrical Faults at Some Selected Buses on the Performance of the Nigerian 330-kV Transmission System," International Journal of Applied Engineering Research, vol. 11, no. 7, pp. 5110-5122, 2016.

[7] N. P. Reform. (2019). Available: www.nigeriapowerreform.org

[8] T. W. Bank. (2019). Electric power consumption (kWh per capita). Available: https://data.worldbank.org/indicator/EG.USE.ELEC.KH.PC

[9] IndexMundi. (2019). Available: www.indexmundi.com

[10] D. F. Warne, Newnes Electrical Power Engineer’s Handbook (Second edition). Newnes, June 27, 2005

[11] DiamondPower. (2019). Conductor Technical Catalogue. Available: http://www.dicabs.com/

[12] R. Lings, V. Chartier, and P. S. Maruvada, "Overview of Transmission Lines Above 700 kV," in IEEE PES 2005 Conference and Exposition in Africa, Durban, South Africa, 11-15 July, 2005.

[13] B. L. Theraja and A. K. Theraja, A Textbook Of Electrical Technology. S. Chand Publishing, 2006.

[14] D. lee, "Korea Corner: 765kV Transmission Technology Development in Korea," EINA, no. 17, pp. 35-38, 2010.

[15] P. R. I. Electric, Transmission LIne Reference Book: 345 kV and Above. Second Edition, revised, EL-2500, 1982.

[16] D. J., Glover, S. Mulukutla, Sarma, and O. Thomas, "Power system analysis and design," 2011, p. 117.

[17] I. o. E. a. E. Engineering, National Electricity Safety Code (NESC). New York: IEEE, 1997.

[18] R. B. Laughlin, "Standard Parameters of 800 kV Class Transmission Systems in India," Accessed on: December 21, Available: http://large.stanford.edu/publications/coal/references/cea/

[19] T. Alumona, L, "Overview Of Losses And Solutions In Power Transmission Lines," IISTE, vol. 4, no. 8, pp. 24-31, 2014.

[20] P. Varun and G. J., Jamnani, "Improving Power Transfer Capability of EHV AC Double circuit Transmission line by Enhancing Surge Impedance Loading level," International Journal of Engineering Research and Development, pp. 41-48, April, 2015.