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Effects of Ground Resistivity and Tower Structural Design on Transmission Line Symmetrical Components

Lambe Mutalub Adesina, Ademola Abdulkareem, Olalekan Ogunbiyi

Abstract*: Electric power transmission towers are line support that exists in different structural configurations depending on the design. Parameters in consideration for the design include proposed voltage and current ratings to be carried by the tower, weight of aluminum conductor and the weight of concrete foundation on which the tower would be erected. It is often reported that ground resistivity of the ground on which an electric power transmission tower is erected has significant effects on earth faults and transmission losses on the line. This paper presents an investigation of the effects of ground resistivity and tower structural design on transmission line symmetrical components. Symmetrical component parameters' evaluation of the transmission lines approach is considered the best option. Ten differently structured transmission towers were selected for the case study. The effects of installing these ten towers on each of the available ground resistivity types were examined. A modern computer software was developed in carrying out this investigation. The results are presented and discussed. It was observed that at each location of a tower, ground resistivity plays a vital role in measuring the performance of tower in an electric power supply stability and reliability.

Keywords: Computer software; Concrete foundation; Earth faults; Ground resistivity; Power transmission tower; Structural configuration; Transmission losses.

I. INTRODUCTION

Transmission towers are generally tall structures usually made up of a steel lattice tower which are used to support an overhead power line in transmitting electrical energy. These towers are available in a wide variety of shapes. The height of the towers are between 15 to 55m. Although, the tallest towers carry 370m height and are in 2,700 m span of Zhoushan Island Overhead power tie [1]. Transmission towers are categorized according to their designed functions, namely transposition, terminal, tension, and suspension activities [2] – [4]. However, some transmission towers are known to be performing more than one functions [1], [3].

Underground power transmission is the alternative to an overhead power transmission. It involves a demonstration of higher technology in fire prevention and also makes the power line less susceptible to outages particularly during high wind thunderstorms or heavy snow or ice storms. Another advantage of an underground power transmission is the aesthetic quality of the landscape or the neatness of the power system environment without the power lines appearing physically [4]. The disadvantage of an underground power transmission is that it increases the costs of electric power transmission both at the design and project implementation stages. But later it may eventually decrease the operation costs over the lifetime of the cables because faults often occur in overhead power line than underground power transmission.

In Nigeria for example, big lattice towers are used for conveying power lines of high voltage such as 132kV and extra high voltage lines of 330kV, while Small lattice towers are used for conveying power lines of medium voltages usually 66 and 33 kV. The towers are designed such that it carries three conductors or multiple of three conductors which could be bundled conductors or double circuits. Tower structures are steel lattices or trusses and attached to it are the insulators bare made of either glass or porcelain disc or composite insulators assembled in strings or long rods whose length are dependent on the line voltage is carrying and environmental conditions. Also placed on top of a tower are one or two ground wire called guard wires. These wire(s) intercept lightning and divert it to the ground. In practice, high and extra-high voltage towers are usually designed to carry two or more electric circuits but for economic reasons, not all these circuits would be used at the start. Towers design, erection and installation technology as well as their post installation performance measure are contained in the brochure of tower manufacturers. [5]. Field Engineers often used load/voltage monitoring as well as load/line parameters' determination techniques to achieve target post Installation performance requirements [5], [6], [7].

The electrical parameters that defines the transmission line are power ratings, propagation constants, shunt admittances, impedances, and characteristic impedances [2], [8]. Efficiency and protection of transmission network are a times carried out through system study of the mentioned electrical parameters above [1], [8], [9]. Literarily, conveyance of energy or power by an overhead transmission lines at high voltage from one station to the other minimized energy losses (or leakages) which could be due to grounding at each tower in the network in addition to voltage reduction with increase in distance travelled [10] –

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***** Correspondence Author

Lambe Mutalub Adesina*, Electrical and Computer Engineering, Kwara State University, Malete, Kwara State, Nigeria. E-mail: lambe.adesina@kwasu.edu.ng

Ademola Abdulkareem, Department of Electrical and Information Engineering, Covenant University, Sango - Ota, Nigeria. E-mail: ademola.abdulkareem@covenantuniversity.edu.ng

Olalekan Ogunbiyi, Electrical and Computer Engineering, Kwara State University, Malete, Kwara State, Nigeria. E-mail: biyikan@gmail.com

[14]. Transmission lines are suspended from insulators while the insulators too are in turns themselves supported by towers. Every span has its own designed value depending on specification of the allowable sag in the network. For example, a modern steel towers carrying high voltage transmission lines, the span is normally 370 – 460 m [2] and with other parameters, the required sag can be evaluated [15]. In order to transmit very high voltage over a long distance, direct current is recommended in such transmission networks [16].

A typical transmission line has resistance, inductance, capacitance and conductance [5]. Conductance between the conductors or between conductors and the ground necessitate the leakage current at the insulators of overhead lines. However, because the current leakage at insulators of overhead lines is negligible, therefore the conductance between conductors of an overhead line is practically assumed to be zero [7], [8]. The resistance and inductance are uniformly distributed along the lines and formed the series impedance. While, the conductance and capacitance are also uniformly distributed along the line and formed the shunt admittance [12]. In summary, a typical overhead transmission line therefore comprises support structures, conductors, Insulators and shield wires [8].

II. THEORY OF TOWER AND TRANSMISSION PARAMETERS

The transmission line parameters evaluation would normally require input data such as conductor parameters which entail conductor sizes, radius, and Geometric mean radius (GMR). Other parameters that may also be necessary include voltage rating, current rating etc. and the ground resistivity of the soil on which the towers are situated. Transmission tower with two-bundle conductors per phase is often very commonly used worldwide except in very European Countries. Thus, to estimate the parameters of such bundle conductors, the values of the Geometric mean diameter (GMD) between the phases as well as the distance between the bundled conductors need to be evaluated, respectively. Therefore, using equations (1) and (2) [1], [10], [13],

$$GMR\,1 = GMR \times D)^{1/2} \tag{1}$$

$$RD1 = (RD \times D)^{1/2} \tag{2a}$$

The equivalent GMR and equivalent radius for each tower can be calculated. D is the distance between the conductors in the bundle. Usually, this is taken to be one-tenth or less than the spacing between phases (DP) [1] i.e.

$$D = \frac{1}{10}(DP)$$
(2b)

The Capacitance, Impedance, Characteristic impedance, and Propagation constant parameters could be evaluated in terms of symmetrical component i.e. positive and zero sequences. Therefore, equation (3) and (4) to (8) could be evaluated to have symmetrical components of impedance and capacitance as well as the value of AC resistance on the line [1], [13].

$$Z_1 = R_{ac} + j2w10^4 \times In\left(\frac{DP}{GMR\,1}\right)\ per\ km \tag{3}$$

$$Z_1(Real) = R_{ac} \tag{3a}$$

$$Z_1(Imag) = 2w10^4 \times In\left(\frac{DP}{GMR\,1}\right) \tag{3b}$$

$$Z_0 = R_{ac} + 1.5w10^4 + j6w10^4 \times \frac{In\left(659\frac{f}{p}\right)^{\frac{1}{3}}}{(GMRI\ X\ (DP)^2)^{\frac{1}{3}}} \tag{4}$$

$$Z_0(Real) = R_{ac} + 1.5w10^4 \tag{4a}$$

$$Z_0(Imag) = 6w10^4 \times \frac{In\left(659\frac{f}{p}\right)^{\frac{1}{3}}}{(GMRI\ X\ (DP)^2)^{\frac{1}{3}}} \tag{4b}$$

Where,
R_{ac} = Power Loss in conductor/RMS current passing through = P/I^2

This resistance is equal to the dc resistance of the conductor only if the distribution of current throughout the conductor is uniform. Thus, dc resistance is given as

$$R_{dc} = \frac{\rho l}{A}\ \Omega \tag{5}$$

Where,
ρ = Resistivity of conductor and has a value of 2.38 x 10^{-8} meter-ohm for aluminum at 20^0 c
l = Transmission line length
A = Cross-sectional area
Therefore,

$$R_{ac} = 1.1R_{dc} \tag{6}$$

$$C_1 = 2\Pi\epsilon o\left[\frac{1}{In\left(\frac{DP}{RD1}\right)}\right]\text{seimen/km} \tag{7}$$

$$C_0 = \left[\frac{2\Pi\epsilon o}{In\left[\frac{(2H)^3}{RD1\ X\ DP^2}\right]}\right]\text{seimen/km} \tag{8}$$

But $C_1 = C_2$

The physical constant ϵ_o commonly called the Vacuum permittivity, permittivity of free space or electric constant or the distributed capacitance of the vacuum is an ideal (baseline) physical constant which is the value of the absolute dielectric permittivity of classical vacuum. Its CODATA value is $\epsilon o = 8.8541878128 \times 10^{-12}$ Farads per meter with relative uncertainty of 1.5×10^{-10}. In modern usage dielectric constant typically refers exclusively to relative permittivity Є/ Єo. Relative permittivity of a material is its (absolute) permittivity expressed as a ratio relative to the vacuum permittivity.

$$\epsilon = \epsilon_r \epsilon_o$$
(8a)

Where,

$\epsilon = \text{the permittivity}$

$\epsilon_r = \text{Relative static permittivity}$

In the vacuum of classical electromagnetism, the polarization $p = 0$, so $\epsilon_r = 1$ and $\epsilon = \epsilon_o$

H_1, H_2, and H_3 are the heights of the three-phase conductors from the ground while DP12, DP23 and DP13 are the spacing between the phases. Therefore, equivalent H and DP can be evaluated using equations (8a) and (8b) as follows [1], [13].

$$H = (H_1 \times H_2 \times H_3)^{\frac{1}{3}} \qquad (8b)$$

$$Dp = (DP_{12} \times DP_{23} \times DP_{13})^{\frac{1}{3}} \qquad (8c)$$

Propagation constant (Q) is the developmental changes happening in transmitted waves as it moves along the line. It's often represented in polar form. The real part is called the attenuation constant while the imaginary part is called the angular phase shift. Mathematically represented by equation (9) [1].

$$Q = A + jb$$

$$= ((R + jwL)\,(G + jwC))^{0.5} = (Z \times Y)^{1/2} \qquad (9)$$

Where,

R = Resistance of the line
L = Inductance of the line
G = Conductance of the line
C = Capacitance of the line
Z = Impedance of the line
Y= Admittance of the line

Considering an infinite length of a transmission line, the input impedance of such line is referred to as Characteristic impedance (Z_c) of the line and it is often represented by equation (10) [1];

$$Z_c = \left(\frac{(R + jwL)}{(G + jwC)}\right)^{\frac{1}{2}} = \left(\frac{Z}{Y}\right)^{\frac{1}{2}} \qquad (10)$$

But, for a transmission line without losses, R = 0, G = 0. Therefore, the characteristic impedance (Z_c) is called Surge impedance (Z_0) and it is represented by equation (11)

$$Z_0 = \left(\frac{L}{C}\right)^{\frac{1}{2}} \qquad (11)$$

Transmission network carries a line voltage (V) at current (I) depending on the size of conductor used. Therefore, Apparent power of the line at a particular tower structure using equation (12) [1], [10], [13] is given by;

$$S = \sqrt{3}\, IV Cos\theta \qquad (12)$$

Where,

$S = \text{Apparent power.}$
$Cos\theta = \text{Power factor}$

Other data also needed for the parameters' analysis for any tower structure are conductor resistance in ohms/km, the size of conductor, Number of strand in Conductor, the corresponding GMR/RD and Current/Voltage ratings of this conductor. The very common values of differently existing ground resistivity are shown in table 1.

Table 1: Earth Resistivity Values Used in Computation [2]

No	Nature of ground	Earth Resistivity (B) in meter ohms
1.	Seawater	0.1
2.	Swampy ground	50
3.	Dry earth	10^3
4.	Pure slate	10^7
5.	Sandstone	10^8
6.	General average	10^2

III. DEVELOPMENT OF ALGORITHM AND FLOWCHART FORMULATION

1. Obtain the designed structural diagram of transmission towers to be used in the analysis.
2. Obtain available different ground resistivity values on which the towers could be erected.
3. Decide the bundle conductors per phase of the chosen transmission tower. Bearing in mind that bundle conductors can be any of these numbers: 2, 3, 4, 5, etc. In this research work, bundle conductors are assumed to be 2.
4. Get the required data of the chosen conductor. These data include voltage rating, geometric mean radius, current rating, radius, conductor size, etc.
5. Software development for symmetrical component parameters' calculations using the algorithm below:
   a) Start
   b) Input conductor and tower data of each of the ten towers:

- Number of bundles conductor per phase
- Distance between bundled conductors
- Choosing conductor radius (RD)
- Choosing conductor diameter (D)
- Geometric mean radius (GMR)
- Height (h) of each bundle conductor per phase to the ground
- Space (DP) between phases A, B, and C of each tower
- Permittivity of Free Space, $\epsilon_o = 8.8541878128 \times 10^{-12}$ F/m

c) Set counter I = 1 to 10 step 1
d) Compute Original GMR, GMR(I) and Original Radius, RD(I) of each tower by equation (1) and (2a) respectively.
e) Compute Original height G. M. H (I) of the 3-phase conductors from the ground, the Original space, G.M.DP(I) between the 3-phase and Original Bundle conductor distances, by equation (8b), (8c) and (2b) respectively.

f) Compute AC resistance (R_{ac}) of the line by equation (6)

g) C_1 and C_0 using equation (7) and (8) respectively.

h) Next, I

i) Evaluating symmetrical component parameters of 10 towers which are different in structural design, considering a specified ground resistivity B(I) at a time.

j) Set counter I = 1 to 6 step 1

k) B(I) =1: Ground Resistivity 1.

l) Compute Z_1 and Z_0 by equation (3) and (4) respectively.

m) Compute propagation constant, Q (I) and Characteristic Impedance, Z_c(I), by equation (9) and (10) respectively.

n) Compute S(I) using equation (12): Apparent power calculation

o) Next I.

p) Is B(I) = N? : Number of tower ground resistivity, N = 6

q) If No, then I = I +1, Goto Step 5K.

r) If Yes, then Goto Step 5S.

s) Print Symmetrical component Parameters for all B(I): All tower ground resistivity

t) End

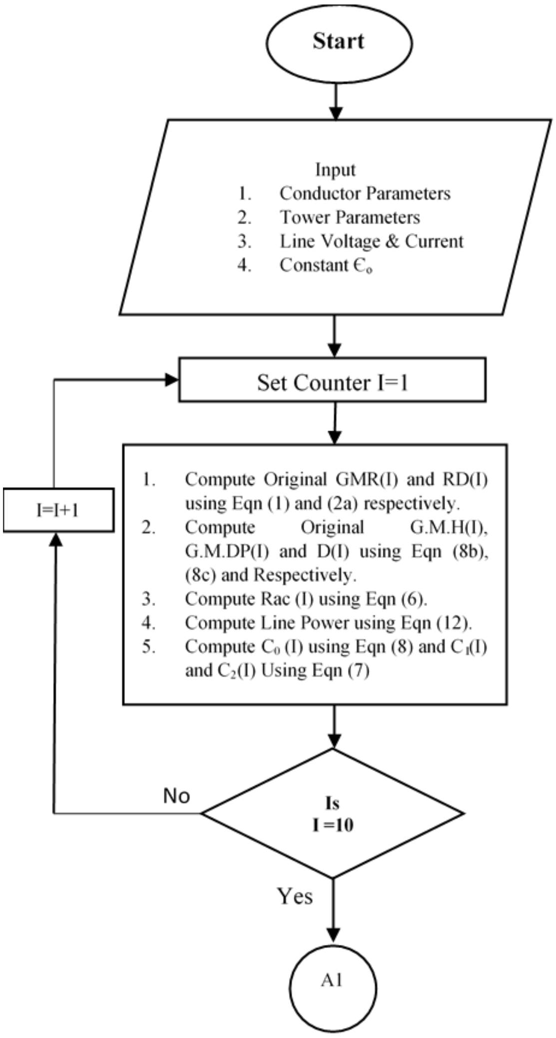

Fig. 1a: Showing the flowchart of the procedures involved in this research

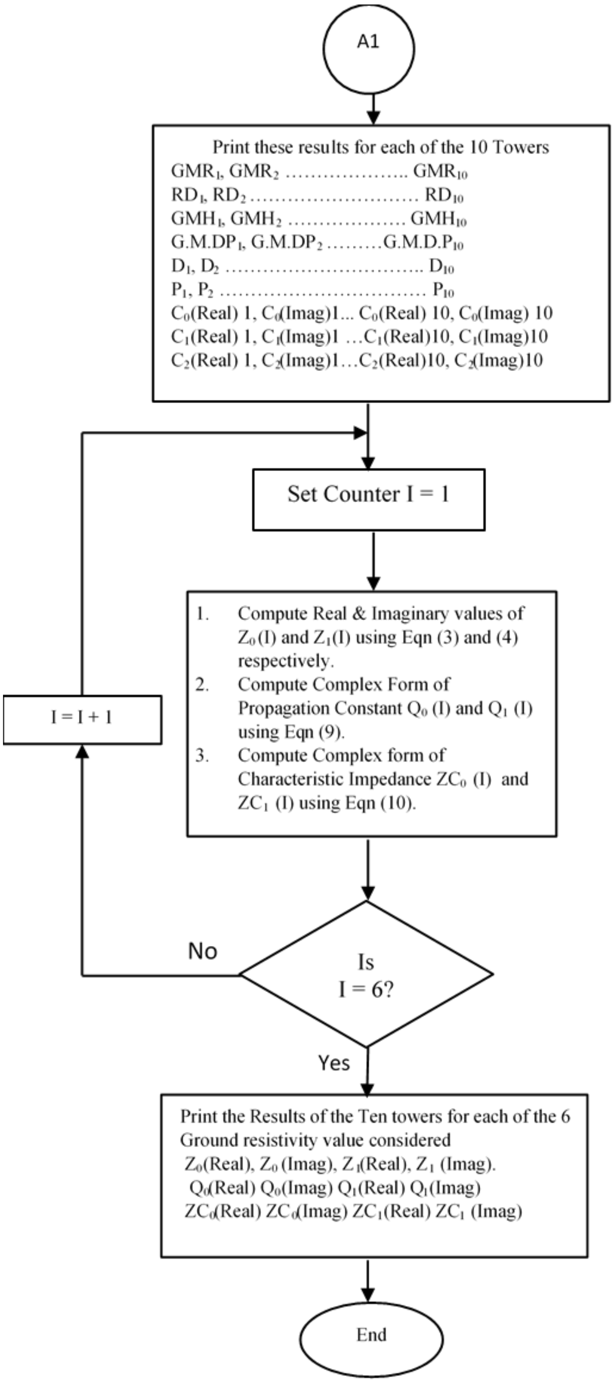

Fig. 1b: Continuation of flowchart showing the procedures involved in this research

IV. APPLICATION OF ALGORITH AND FLOWCHART TO CASE STUDY

In this section, an application of the developed algorithm and the formulated Flowchart to the selected case study transmission towers are presented in subsections **A** while the results are presented in subsection **B**.

A. Application of Developed Algorithm to Case Study

The developed algorithm and Flowchart formulated in Section 4 above were applied to Case study described below.

Ten differently structured transmission towers shown in Figures 2 to 11, which are commonly used in Nigeria are selected as case study. The article investigates the variation of symmetrical component parameters on the transmission lines been carried by each of these towers when they are installed on grounds having the ground resistivity listed in table 1 above. This is done by first considering the variation of these parameters when all the ten towers were installed on first selected ground resistivity. Later, other ground resistivity were considered one after the other. Focusing back to section 3.0 where parameters of towers were extensively discussed, the dimensions here assisted in calculating other towers parameters which are presented in tables 2 and 3 of the results. To fully achieve the objectives of this paper, a computer software in Python was developed and run. The results obtained are presented subsection 4.2. Two assumptions were taken. The distance D is taken to be 1/25 of DP while the permittivity of Free Space, Єo , is taken as 8.8541878128 x 10^{-12} F/m

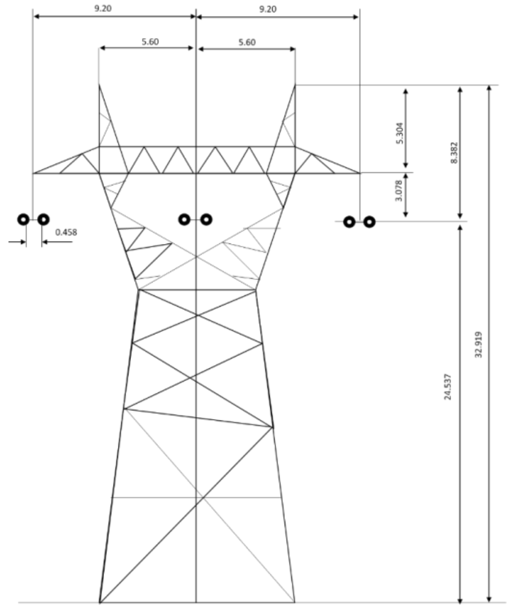

Fig. 2: Tower 1

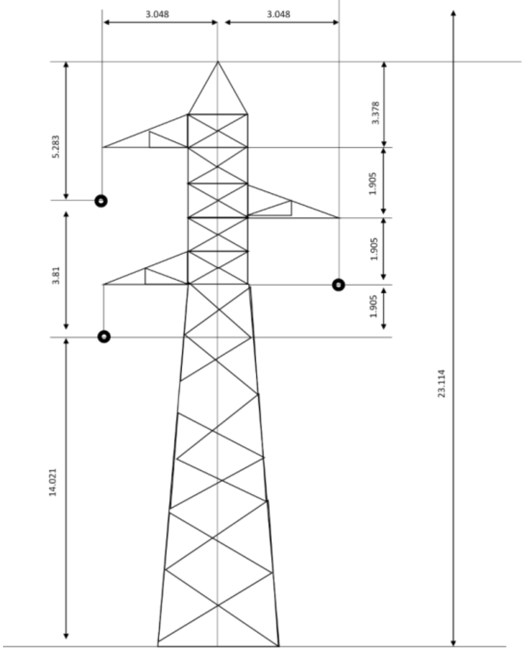

Fig. 3: Tower 2

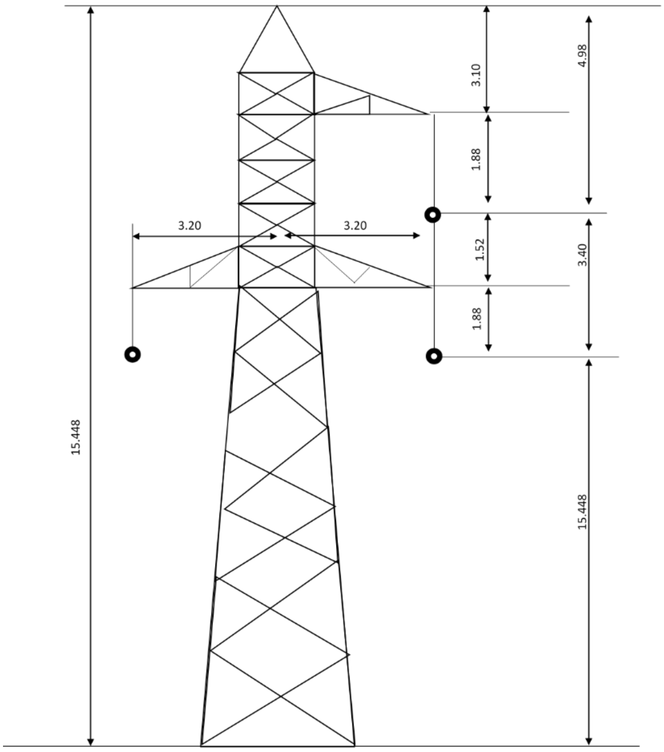

Fig. 4: Tower 3

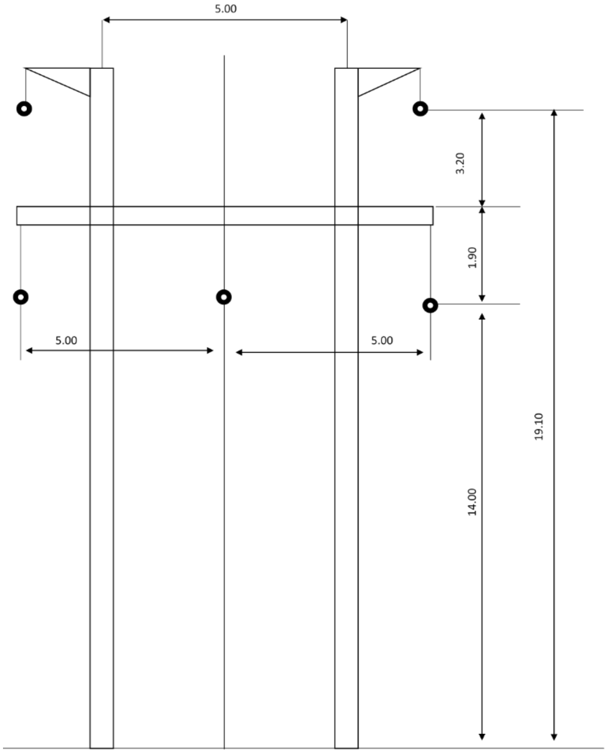

Fig. 5: Tower 4

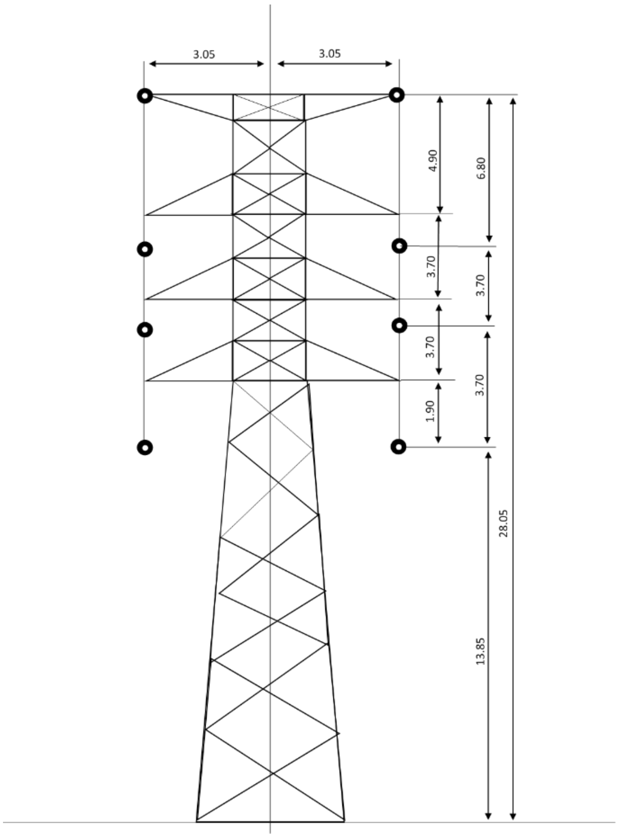

Fig. 6: Tower 5

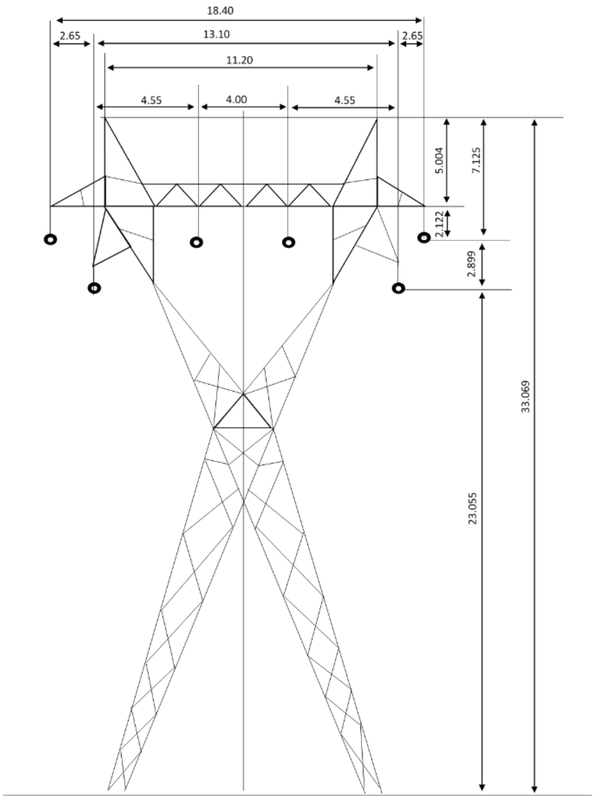

Fig. 7: Tower 6

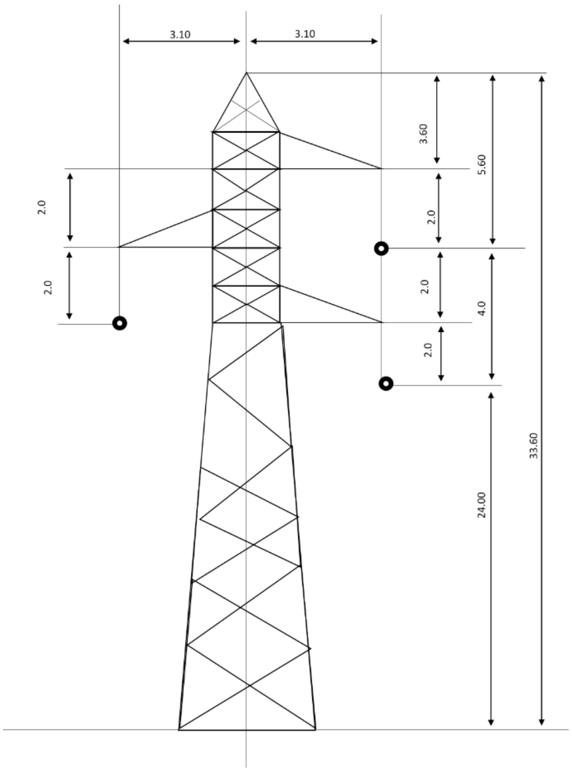

Fig. 8: Tower 7

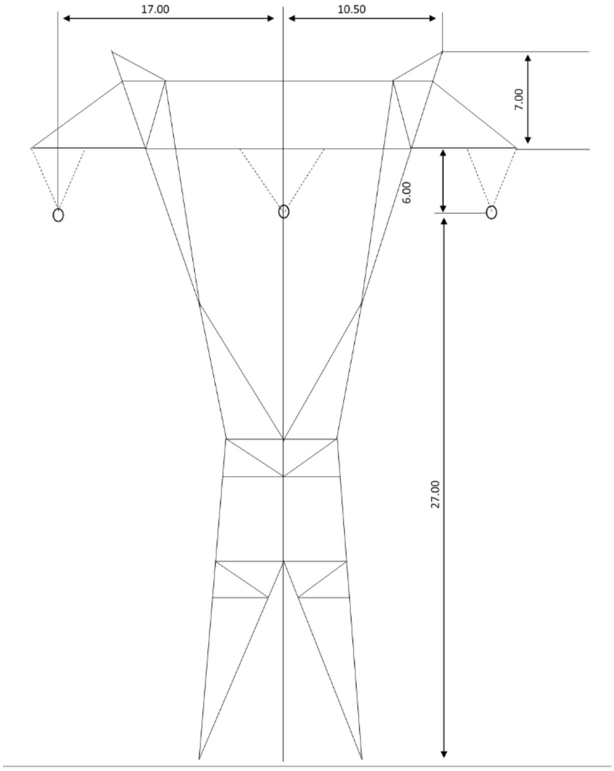

Fig. 9: Tower 8

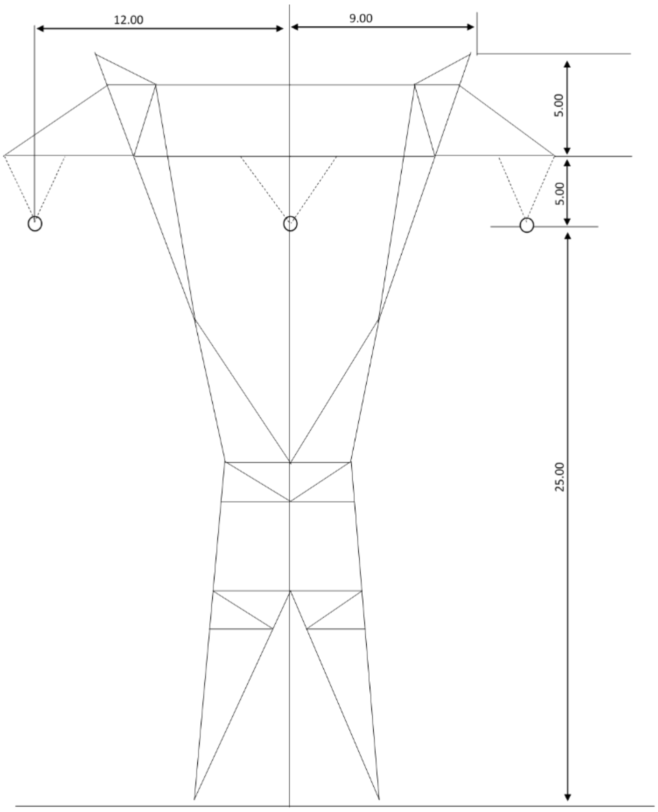

Fig. 10: Tower 9

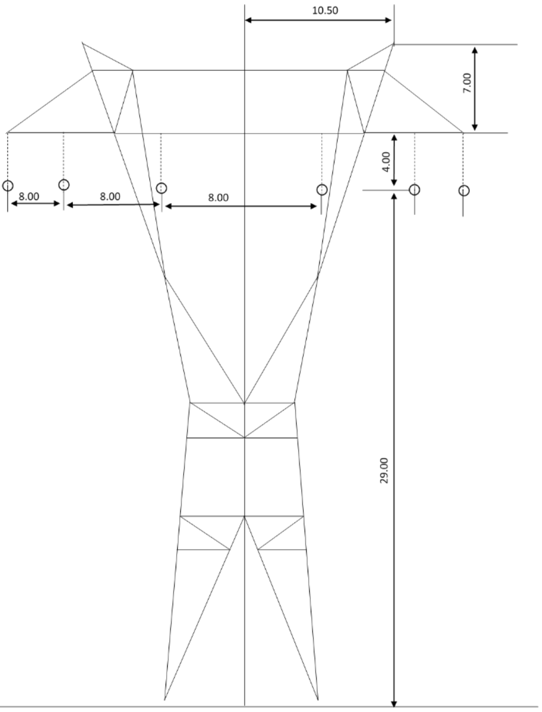

Fig. 11: Tower 10

B. Presentation of Results

The results of the analysis are shown in Table 2 to 11f. These results are for the 10 number differently structured towers at each of the ground resistivity listed in table 1 above for this investigation analysis.

Table 2: Original Towers' Parameters

Tower Number	Original radius (meters)	Original G.M.R (METERS)
1	0.0831	0.07327
2	0.03874	0.03419
3	0.03875	0.03419
4	0.04169	0.03679
5	0.03587	0.03165
6	0.038761	0.0342
7	0.04223	0.03726
8	0.11539	0.10185
9	0.09697	0.08559
10	0.07983	0.07039

Table 3: Bundled Conductors and Tower Height Parameters

Tower Number	G.M.H (meters)	G. M. DP (meters)	Bundle cond. dist. (meters)
1	24.4586	11.56291	0.46252
2	15.80594	5.43061	0.21722
3	16.46085	5.43118	0.21725
4	13.9631	6.28802	0.25152
5	17.23684	4.65454	0.18618
6	24.86276	5.43406	0.21736
7	25.86426	6.45183	0.25807
8	26.9116	21.35313	0.85413
9	24.91966	15.07805	0.60312
10	28.90251	10.67164	0.42687

Table 4: Current, Voltage and Calculated Power Rating

Tower Number	Current ratings (A)	Voltage ratings (kV)	Power ratings (MVA)
1	1330	330	760.1748
2	393.6	132	89.9864064
3	393.6	132	89.9864064
4	393.6	132	89.9864064
5	393.6	132	89.9864064
6	393.6	132	89.9864064
7	393.6	132	89.9864064
8	1466	700	1777.3784
9	1466	500	1269.556
10	1330	330	760.1748

Table 5: Symmetrical Components C_o, C_1 and C_2 of Line Capacitive Susceptance

Tower Number	C_0	C_1	C_2
1	0.57235	0.94465	0.94465
2	0.52580	0.94257	0.94257
3	0.52050	0.94256	0.94256
4	0.55678	0.92229	0.92229
5	0.50192	0.96489	0.96489
6	0.47216	0.94248	0.94248
7	0.48027	0.91882	0.91882
8	0.62866	0.87008	0.87008
9	0.60305	0.91412	0.91412
10	0.53984	0.95618	0.95618

B(1) = 0.1

Table 6a: Symmetrical Components Z_o, Z_1 and Z_2 of Line Impedances

Tower Number	Z_0 Real	Z_0 Imag.	Z_1 Real	Z1 Imag
1	0.00083	2.65878	0.02594	0.49890
2	0.00133	2.54780	0.0415	0.46231
3	0.00133	2.54782	0.0415	0.46232
4	0.00133	2.57667	0.0415	0.47675
5	0.00133	2.51743	0.0415	0.44711
6	0.00133	2.54792	0.0415	0.46237
7	0.00133	2.58173	0.0415	0.47929
8	0.00052	2.77735	0.0163	0.55713
9	0.00052	2.70882	0.0163	0.52283
10	0.00052	2.64298	0.0163	0.49100

Table 6b: Symmetrical Components Q_0 and Q_1 of Propagation Constants

Tower Number	Q_0 Real	Q_0 Imag	Q_1Real	Q_1 Imag
1	4.76586E-4	1.52177	0.02450	0.47129
2	7.00446E-4	1.33963	0.03911	0.43576
3	6.93392E-4	1.32615	0.03911	0.43576
4	7.41723E-4	1.43465	0.03827	0.43971
5	6.68645E-4	1.26357	0.04004	0.43141
6	6.28991E-4	1.20303	0.03911	0.43577
7	6.39802E-4	1.23995	0.03813	0.44038
8	3.28936E-4	1.74602	0.01418	0.48475
9	3.15536E-4	1.63357	0.01490	0.47793
10	2.82461E-4	1.42679	0.01558	0.46948

Table 6c: Symmetrical Components ZC_0 and ZC_1 of Characteristic Impedances

Tower Number	ZC_0 Real	ZC_0 Imag	ZC_1 Real	ZC_1 Imag
1	0.00145	4.64532	0.02745	0.52813
2	0.00253	4.84556	0.04402	0.49047
3	0.00255	4.89490	0.04402	0.49049
4	0.00239	4.62775	0.04499	0.51692
5	0.00265	5.01551	0.04300	0.46337
6	0.00282	5.39629	0.04403	0.49058
7	0.00277	5.37551	0.04516	0.52163
8	8.32288E-4	4.41786	0.01873	0.64032
9	8.67632E-4	4.49184	0.01783	0.57195
10	9.69226E-4	4.89584	0.01704	0.51350

B(2) = 50

Table 7a: Symmetrical Components $Z_{0,}$ Z_1 and Z_2 of Line Impedances

Tower Number	Z_0 (Real)	Z_0 (Imag)	Z_1 (Real)	Z1 (Imag)
1	0.00083	2.65878	0.02594	0.49890
2	0.00133	2.54780	0.0415	0.46231
3	0.00133	2.54782	0.0415	0.46232
4	0.00133	2.57667	0.0415	0.47675
5	0.00133	2.51743	0.0415	0.44711
6	0.00133	2.54792	0.0415	0.46237
7	0.00133	2.58173	0.0415	0.47929
8	0.000523	2.77735	0.0163	0.55713
9	0.000523	2.70882	0.0163	0.52283
10	0.000523	2.64298	0.0163	0.49100

Table 7b: Symmetrical Components Q_0 and Q_1 of Propagation Constants

Tower Number	Q_0 (Real)	Q_0 (Imag)	Q_1 (Real)	Q_1 (Imag)
1	4.76586E-4	1.52177	0.02450	0.47129
2	7.00446E-4	1.33963	0.03911	0.43576
3	6.93392E-4	1.32615	0.03911	0.43576
4	7.41723E-4	1.43465	0.03827	0.43971
5	6.68645E-4	1.26357	0.04004	0.43141
6	6.28991E-4	1.20303	0.03911	0.43577
7	6.39802E-4	1.23995	0.03813	0.44038
8	3.28936E-4	1.74602	0.01418	0.48475
9	3.15536E-4	1.63357	0.01490	0.47793
10	2.82461E-4	1.42679	0.01558	0.46948

Table 7c: Symmetrical Components ZC_0 and ZC_1 of Characteristic Impedances

Tower Number	ZC_0 (Real)	ZC_0 (Imag)	ZC_1 (Real)	ZC_1 (Imag)
1	0.00145	4.64532	0.02745	0.52813
2	0.00253	4.84556	0.04402	0.49047

3	0.00255	4.89490	0.04402	0.49049
4	0.00239	4.62775	0.04499	0.51692
5	0.00265	5.01551	0.04300	0.46337
6	0.00282	5.39629	0.04403	0.49058
7	0.00277	5.37551	0.04516	0.52163
8	8.32288E-4	4.41786	0.01873	0.64032
9	8.67632E-4	4.49184	0.01783	0.57195
10	9.69226E-4	4.89584	0.01704	0.51350

B (3) = 1000

Table 8a: Symmetrical Components Z_0, Z_1 and Z_2 of Line Impedances

Tower Number	Z_0 (Real)	Z_0 (Imag)	Z_1 (Real)	Z1 (Imag)
1	0.00083	1.77293	0.02594	0.49890
2	0.00133	1.66195	0.0415	0.46231
3	0.00133	1.66197	0.0415	0.46232
4	0.00133	1.69082	0.0415	0.47675
5	0.00133	1.63158	0.0415	0.44711
6	0.00133	1.66207	0.0415	0.46237
7	0.00133	1.69588	0.0415	0.47929
8	0.00052	1.89150	0.0163	0.55713
9	0.00052	1.82297	0.0163	0.522838
10	0.00052	1.75713	0.0163	0.491001

Table 8b: Symmetrical Components Q_0 and Q_1 of Propagation Constants

Tower Number	Q_0 (Real)	Q_0 (Imag)	Q_1 (Real)	Q_1 (Imag)
1	4.76586E-4	1.01474	0.02450	0.47129
2	7.00446E-4	0.87385	0.03911	0.43576
3	6.93392E-4	0.86506	0.03911	0.43576
4	7.41723E-4	0.94142	0.03827	0.43971
5	6.68645E-4	0.81893	0.04004	0.43141
6	6.28991E-4	0.78477	0.03911	0.43577
7	6.39802E-4	0.81449	0.03813	0.44038
8	3.28936E-4	1.18911	0.01418	0.48475
9	3.15536E-4	1.09935	0.01490	0.47793
10	2.82461E-4	0.94857	0.01558	0.46948

Table 8c: Symmetrical Components ZC_0 and ZC_1 of Characteristic Impedances

Tower Number	ZC_0 (Real)	ZC_0 (Imag)	ZC_1 (Real)	ZC_1 (Imag)
1	0.00145	3.09759	0.02745	0.52813
2	0.00253	3.16079	0.04402	0.49047
3	0.00255	3.19299	0.04402	0.49049
4	0.00239	3.03674	0.04499	0.51692
5	0.00265	3.25061	0.04300	0.46337
6	0.00282	3.52013	0.04403	0.49058
7	0.00277	3.53105	0.04516	0.52163
8	8.32288E-4	3.00876	0.01873	0.64032
9	8.67632E-4	3.02290	0.01783	0.57195
10	9.69226E-4	3.25489	0.01704	0.51350

B (4) = 10000000

Table 9a: Symmetrical Components Z_0, Z_1 and Z_2 of Line Impedances

Tower Number	Z_0 (Real)	Z_0 (Imag)	Z_1 (Real)	Z1 (Imag)
1	0.00083	-0.95061	0.02594	0.49890
2	0.00133	-1.06159	0.0415	0.46231
3	0.00133	-1.06157	0.0415	0.46232
4	0.00133	-1.03272	0.0415	0.47675
5	0.00133	-1.09196	0.0415	0.44711
6	0.00133	-1.06146	0.0415	0.46237
7	0.00133	-1.02765	0.0415	0.47929
8	0.00052	-0.83204	0.0163	0.55713
9	0.00052	-0.90057	0.0163	0.52283
10	0.00052	-0.96641	0.0163	0.49100

Table 9b: Symmetrical Components Q_0 and Q_1 of Propagation Constants

Tower Number	Q_0 (Real)	Q_0 (Imag)	Q_1 (Real)	Q_1 (Imag)
1	4.76586E-4	-0.54409	0.02450	0.47129
2	7.00446E-4	-0.55818	0.03911	0.43576
3	6.93392E-4	-0.55255	0.03911	0.43576
4	7.41723E-4	-0.57500	0.03827	0.43971
5	6.68645E-4	-0.54808	0.04004	0.43141
6	6.28991E-4	-0.50118	0.03911	0.43577
7	6.39802E-4	-0.49356	0.03813	0.44038
8	3.28936E-4	-0.52307	0.01418	0.48475
9	3.15536E-4	-0.54309	0.01490	0.47793
10	2.82461E-4	-0.52171	0.01558	0.46948

Table 9c: Symmetrical Components ZC_0 and ZC_1 of Characteristic Impedances

Tower Number	ZC_0 (Real)	ZC_0 (Imag)	ZC_1 (Real)	ZC_1 (Imag)
1	0.00145	-1.66087	0.02745	0.52813
2	0.00253	-2.01900	0.04402	0.49047
3	0.00255	-2.03950	0.04402	0.49049
4	0.00239	-1.85479	0.04499	0.51692
5	0.00265	-2.17553	0.04300	0.46337
6	0.00282	-2.24810	0.04403	0.49058
7	0.00277	-2.13971	0.04516	0.52163
8	8.32288E-4	-1.32351	0.01873	0.64032

9	8.67632E-4	-1.49334	0.01783	0.57195
10	9.69226E-4	-1.79017	0.01704	0.51350

B (5) = 10^8

Table 10a: Symmetrical Components Z_0, Z_1 and Z_2 of Line Impedances

Tower Number	Z_0 (Real)	Z_0 (Imag)	Z_1 (Real)	Z1 (Imag)
1	0.00083	-1.6315	0.02594	0.49890
2	0.00133	-1.7424	0.0415	0.46231
3	0.00133	-1.7424	0.0415	0.46232
4	0.00133	-1.7136	0.0415	0.47675
5	0.00133	-1.7728	0.0415	0.44711
6	0.00133	-1.7423	0.0415	0.46237
7	0.00133	-1.7085	0.0415	0.47929
8	0.00052	-1.5129	0.0163	0.55713
9	0.00052	-1.5814	0.0163	0.52283
10	0.00052	-1.6472	0.0163	0.49100

Table 10b: Symmetrical Components Q_0 and Q_1 of Propagation Constants

Tower Number	Q_0 (Real)	Q_0 (Imag)	Q_1 (Real)	Q_1 (Imag)
1	4.76586E-4	-0.93380	0.02450	0.47129
2	7.00446E-4	-0.91619	0.03911	0.43576
3	6.93392E-4	-0.90696	0.03911	0.43576
4	7.41723E-4	-0.95411	0.03827	0.43971
5	6.68645E-4	-0.88984	0.04004	0.43141
6	6.28991E-4	-0.82267	0.03911	0.43577
7	6.39802E-4	-0.82057	0.03813	0.44038
8	3.28936E-4	-0.95112	0.01418	0.48475
9	3.15536E-4	-0.95370	0.01490	0.47793
10	2.82461E-4	-0.88928	0.01558	0.46948

Table 10c: Symmetrical Components ZC_0 and ZC_1 of Characteristic Impedances

Tower Number	ZC_0 (Real)	ZC_0 (Imag)	ZC_1 (Real)	ZC_1 (Imag)
1	0.00145	-2.85049	0.02745	0.52813
2	0.00253	-3.31395	0.04402	0.49047
3	0.00255	-3.34762	0.04402	0.49049
4	0.00239	-3.07767	0.04499	0.51692
5	0.00265	-3.53207	0.04300	0.46337
6	0.00282	-3.69015	0.04403	0.49058
7	0.00277	-3.55740	0.04516	0.52163
8	8.32288E-4	-2.40657	0.01873	0.64032
9	8.67632E-4	-2.62240	0.01783	0.57195
10	9.69226E-4	-3.05144	0.01704	0.51350

B (6) = 10^2

Table 11a: Symmetrical Components Z_0, Z_1 and Z_2 of Line Impedances

Tower Number	Z_0 (Real)	Z_0 (Imag)	Z_1 (Real)	Z1 (Imag)
1	0.00083	2.45381	0.02594	0.49890
2	0.00133	2.34283	0.0415	0.46231
3	0.00133	2.34285	0.0415	0.46232
4	0.00133	2.37170	0.0415	0.47675
5	0.00133	2.31246	0.0415	0.44711
6	0.00133	2.34296	0.0415	0.46237
7	0.00133	2.37677	0.0415	0.47929
8	0.00052	2.57238	0.0163	0.55713
9	0.00052	2.50386	0.0163	0.52283
10	0.00052	2.43801	0.0163	0.49100

Table 11b: Symmetrical Components Q_0 and Q_1 of Propagation Constants

Tower Number	Q_0 (Real)	Q_0 (Imag)	Q_1 (Real)	Q_1 (Imag)
1	4.76586E-4	1.40445	0.02450	0.47129
2	7.00446E-4	1.23186	0.03911	0.43576
3	6.93392E-4	1.21947	0.03911	0.43576
4	7.41723E-4	1.32053	0.03827	0.43971
5	6.68645E-4	1.16069	0.04004	0.43141
6	6.28991E-4	1.10625	0.03911	0.43577
7	6.39802E-4	1.14151	0.03813	0.44038
8	3.28936E-4	1.61716	0.01418	0.48475
9	3.15536E-4	1.50996	0.01490	0.47793
10	2.82461E-4	1.31614	0.01558	0.46948

Table 11c: Symmetrical Components ZC_0 and ZC_1 of Characteristic Impedances

Tower Number	ZC_0 (Real)	ZC_0 (Imag)	ZC_1 (Real)	ZC_1 (Imag)
1	0.00145	4.28721	0.02745	0.52813
2	0.00253	4.45574	0.04402	0.49047
3	0.00255	4.50111	0.04402	0.49049

4	0.00239	4.25963	0.04499	0.51692
5	0.00265	4.60715	0.04300	0.46337
6	0.00282	4.96219	0.04403	0.49058
7	0.00277	4.94874	0.04516	0.52163
8	8.32288E-4	4.09183	0.01873	0.64032
9	8.67632E-4	4.15196	0.01783	0.57195
10	9.69226E-4	4.51616	0.01704	0.51350

V. RESULTS AND DISCUSSION

The power rating of any transmission line depends on the size of the conductor of the cable used and the voltage of transmission. As the transmission voltage increases, the size of conductor which will be used also increases, hence power rating of the line increases as shown in Table 4. Looking at Table 5 and the overall results at large, it is observed that the symmetrical components of capacitive Susceptance of the transmission lines on any tower is dependent on the value of tower ground resistivity. From Table 6a to 11c, there is considerable variation of Symmetrical components of impedance, propagation constants and characteristic impedance of the lines on tower as the tower structural design changes even when the ground resistivity of the tower remain the same. For example, in Table 6a to 6c, the tower ground resistivity is the same and has a value of B = 0.1. As shown in table 4, towers designated for extra-high voltages such as tower 1 (330kV), tower 8 (700kV), tower 9 (500kV) and tower 10 (330kV) can be seen on table 6a having lower values of Z0(Rea), high values of Z0(Imag), lower values of Z1 (Real) and higher values of Z1 (Imag). This would further imply that the magnitudes of these towers' parameters will also be higher than other towers as well. In table 6b, the zero sequence propagation constants Q0 (Real) for all the towers, have their values in negative four exponential which of course are values that can be approximated to be zero while the Q0 (Imag) values are higher for extra - high voltage towers as stipulated above. Conversely, the Q1 (Real) values are lower for extra – high voltage towers while the Q1 (Imag) values are relatively constants for all the towers. Table 6c, the characteristic impedance ZC0 (Real) for the 3 most extra – high voltage towers are very low and close to value zero. In ZC0 (Imag), the obtained results have values that have little variations or differences. The ZC1 (Real) values are very low for extra – high voltage towers while the ZC1 (Imag) values are generally high for all the towers regardless of the Structural design.

Looking at table 6a, 7a, 8a, 9a, 10a and 11a for ground resistivity values B1 to B6, it is observed that Z0 (Real), Z0 (Imag), Z1(Real) and Z1 (Imag) values remain unchanged. This imply that a change in ground resistivity of tower has no significant effect on Symmetrical Components of Impedance. Also, cross checking table 6b, 7b, 8b, 9b, 10b and 11b for ground resistivity values B1 to B6, it is observed that as the ground resistivity increases sharply, the values of Q0(Imag) and Q1(Imag) are reduced as shown clearly in tables 6b and 8b at ground resistivity of B1 = 0.1 and B3 = 1000 respectively. While, Q0 (Real) and Q1 (Real) values are relatively constant. This signify that they are independent of tower ground resistivity. This reduction in values continues with increased value of ground resistivity.

Table 6c and 7c explain the behavior of symmetrical characteristic impedance to changes in tower structure as well as tower ground resistivity. From these tables as example, with increase in ground resistivity from B1 = 0.1 to B2 = 50, ZC0 (Real) values are reduced. But, ZC0 (Imag) values are observed to have increased for some of the towers and reduced for the rest of the towers. It however shows that structural design of transmission towers plays a prominent role for these significant changes. ZC1 (Real) values reduced drastically for extra – high voltage towers (i.e tower 1, 8, 9 and 10) but remain constant for the rest of the towers (i.e tower 2, 3,4,5,6 and 7).

VI. CONCLUSION

The paper has presented a thorough investigation of the effects of ground resistivity on ten selected transmission tower structures commonly used in Nigeria. An algorithm was developed and translated to flowchart formulation. Software program developed generated reliable results which have been extensively analyzed. From the results, it was observed that the symmetrical components of transmission line parameters calculated for each tower in the case studied gave the required value for its efficient performance. It was further observed that the resistivity of the ground where the tower is installed is an important parameter that play active role in electric power supply stability and reliability. The observe increase in positive sequence resistance on transmission lines that are solidly earthed with copper wires at every tower is of practical importance in faults minimization. This increase also necessitate the losses caused by the circulating currents in grounding systems.

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AUTHORS PROFILE

Dr. Lambe Mutalub Adesina, Started his academic career as an assistant Lecturer in 1991 with the Department of Electrical Engineering, Kaduna Polytechnic, Kaduna, Nigeria. He became Lecturer II before his new appointment as Manager in 1998 with Power Holding Company of Nigeria (PHCN), an organization that was responsible for generation, transmission, and distribution of electricity in Nigeria. He possessed B. Eng. (Hons) Electrical 1988, M. Eng. (Electrical) 1995 and PhD (Power systems quality) 2016 from University of Ilorin, Bayero University Kano and University of Ibadan respectively. However, all the three Universities are unique in quality and based in Nigeria. He is a corporate member of the Nigeria Society of Engineers (NSE) since 1993 and registered as a member of Council for the Regulation of Engineering in Nigeria (COREN) 1995. He voluntarily resigned his appointment with EKO Electricity Distribution Company, one of the Nigerian Government privatized PHCN distribution companies as Principal Manager (Engineering & Standardization) in 2018. He joined Kwara State University, Malete, Nigeria, as a Senior Lecturer in 2018 and was appointed as Head of Electrical and Computer Engineering Department in April 2019. He has published several academic papers even when he was in the industry in reputable Journals both locally and internationally. He specialized on power system, machines, and renewable energy. He also reviews articles for publications in both local and international journals. He is happily living in Ilorin, Kwara State, Nigeria.

Dr. Ademola Abdulkareem is a Senior Lecturer in the Department of Electrical and Information Engineering, Covenant University, Ota, Nigeria. He obtained B.Eng. in Electrical Engineering from University of Ilorin, Ilorin, Nigeria. He also earned a Master degree (M.Sc.) in 2008 at University of Lagos, Lagos Nigeria, in Electrical and Electronics Engineering. In addition, he holds a PhD degree in Electrical and Electronics Engineering with emphasis in Power System and Machine. He is a corporate member of Nigerian Society of Engineers (MNSE) and registered with the Council for the Regulation of Engineering in Nigeria (COREN). His main research interest includes: Power Systems Quality and Control, High Voltage Engineering, Renewable Energy Integration, Smart Power Distribution System and Intelligent Building, Energy. He has published articles in several leaned journals.

Olalekan Ogunbiyi bagged a Ph.D. degree in Electrical Engineering from University of Ilorin in 2018. Earlier, he obtained his Bachelor’s degree and Master’s degree in Electrical and Electronics Engineering from the same University in 2009 and 2013 respectively. His research interests and specialization include Automatic Control System, Embedded System and Power System Control and Stability. He has published several papers on control of hydropower station under uncertainties, computer networks and power system. Currently, he lectures in the department of Electrical and Computer Engineering, Kwara State University, Nigeria.