Symmetrical Components of Transmission Line Parameters based on the Installed Tower Ground Resistivity

Lambe Mutalub Adesina, Ganiyu Adedayo Ajenikoko, Olalekan Ogunbiyi, Tosin Samuel Oluwafemi

Abstract*: Transmission is a component of the electric power system alongside the generation and distribution systems. Effective and efficient planning is often required in system design and operation to ensure consistent and reliable supply of power to the Customers. Thus, transmission line parameters analysis needs to be carried out to ensure this proper planning. One of the crucial equipment used in transmission's overhead lines is Tower supports which are of different configuration considering the Structural design, voltage ratings and current transmission. Very often, towers are randomly installed to carry lines of the chosen voltage and current rating without considering the effects of earth resistivity on which the tower is installed. This paper presents the transmission line symmetrical component parameters evaluation of a chosen Transmission tower. An algorithm was developed, and python software program was used to implement this algorithm for the analysis. In achieving target, the selected tower was imagined having been erected on six different earth resistivity ground which include, sea water, swampy ground, pure slate, sandstone and general average ground. Symmetrical component parameters evaluated includes impedance, characteristics impedance, propagation constant, shunt admittance and capacitive suceptances as they were found to be important in the effective monitoring of power transmission and distribution. The results of the analysis are presented and discussed. These results show that capacitive suceptances are independent on tower earth resistivity and vary for different tower structural configurations while other parameters vary with earth resistivity value of the tower. Furthermore, regular line parameters monitoring is a measure minimizing power transmission losses in networks.

Keywords*: Earth resistivity, Python software, Structural design, Symmetrical components, Tower support, Transmission line parameters.

I. INTRODUCTION

Exponential rise in demand for electricity day-to-day activities necessitate the Electrical Engineers to embark on a day to day planning of the electric power system to ensure a reliable and quality supply of electricity to its different consumers [1, 2, 3]. In order to achieve this, various techniques and methods are employed which include load and voltage monitoring, load parameters, line parameters etc. [2].

Transmission and distribution voltage level operation vary from one country to another based on the mode of techniques or energy used to generate the electricity. This arises mainly from geographical and historical reasons. Presently in Nigeria, the transmission voltages are 132kV and 330kV while the voltages at the distribution level are 33kV, 11kV and 0.415kV, for different loads in the system and the distribution network is predominantly radial [2,4,5,6]. Generally, the distribution system comprises of 40% of the overall capital investments of total power system. Industrial loads, commercial loads and residential loads are the classification of the load groups of the various consumers. The most stable of all the loads is the Industrial load while the residential loads are the most unstable, due to load changes variation in the system's peak which occur as a result of increase in the load used such as washing machine, pumping machines, electric cooker, refrigerator, fans etc. [7,8, 9].

In order to control and protect networks, systems studies are very important and necessary to increase the efficiency of the system. To carry out these studies, electrical parameters that define the transmission lines, as well as the load characteristics give vital data or information for such studies [5,10]. The line parameters commonly used are characteristic impedances, propagation constants, shunt admittances, impedances and power ratings [4,5].

In order to convey electric power to various destinations, comes the use of tower to transmit energy from one place to another at reduced energy loss or leakages due to grounding at various point at each respective tower point as voltage reduces with increase in distance travelled [11,12, 13]. This is made available through the transmission lines which transmit both the current and voltage from one place to another over a short medium and a long distance. The transmission line typically consists of a conductor having a uniform cross-sectional area along the line and air acting as a dielectric or insulating material or medium between the conductors anchored by supporting structures which is the tower erected at an estimated regular interval [1,4].

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The transmission lines are suspended from insulators of the required rating which are supported by towers. Each span depends on the allowable sag in the line and for the steel towers carrying high voltage lines, the span is normally 370 – 460m. There are two main types of tower. The first is tower meant for straight runs that have the capability to withstand stress due to the weight of the line alone. While to the other one is for changing of route, known as deviation tower. This type of tower has the capacity to withstand the resultant forces set up when the line changes direction [5].

In terms of safety, there is the need to be a considerable distance between the transmission line and the ground. An electrical tower is used for upholding the conductors of the transmission line. A tower is made up of steel which provides high strength to the conductor. In other to transmit high voltage, over a long distance, direct current is used in the transmission line [11].

An electric transmission line has four parameters which affect its ability to perform its required function as part of a power system. These parameters include resistance, inductance, capacitance and conductance [5].Conductance between the conductors or between conductors and the ground accounts for the leakage current at the insulators of overhead lines. Since current leakage at insulators of overhead lines is negligible, the conductance between conductors of an overhead line is assumed to be zero [7,8].However, the resistance and inductance which are uniformly distributed along the line form the series impedance, while the conductance and capacitance are uniformly distributed along the line from the shunt admittance [12]. Generally, an overhead transmission line consists of conductors, insulators, support structures, and, in most cases, shield wires [8].

II. THEORY OF TRANSMISSION LINE PARAMETERS

Very common Nigerian transmission tower is used as a case study. The transmission line symmetrical component parameters evaluation was carried out for the chosen tower structure with the consideration that this tower is installed on six locations of different earth resistivity values according to the constituents of the soil. Required input data include, conductor parameters such as conductor sizes, radius, Geometric mean radius (GMR), voltage rating, current rating etc. and the earth (ground) resistivity of the soil on which the tower is situated.

However, in each case, transmission tower with two-bundle conductors per phase but with same tower structure is considered all through as shown in Figure 1. 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. This research work has earlier stipulated that two-bundle conductors assumed to be composed in each phase of three phase line. Therefore, using equations (1) and (2) [13, 14],

$$GMR\ 1 = (GMR \times D)^{\frac{1}{2}} \quad (1)$$

$$RD\ 1 = (GMR \times D)^{\frac{1}{2}} \quad (2)$$

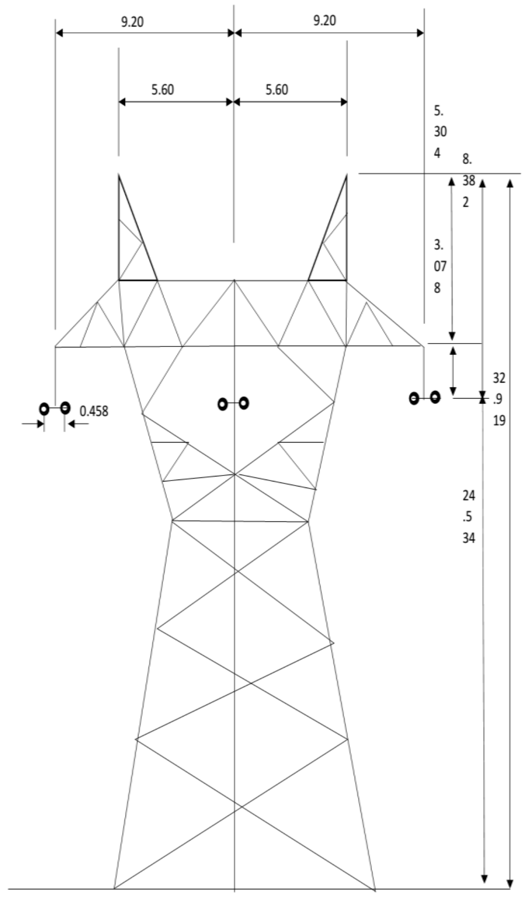

Fig. 1.Showing a typical type of tower used in computation

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) [9, 12, 15]. However, for this research paper, D was assumed as 1/25 of DP. The power rating of each tower can also be evaluated [10].

The parameters such as impedances, capacitive suceptances, propagation constants and characteristic impedances was evaluated in terms of symmetrical component i.e. positive and zero sequence. Equation (3), (4), (7), (8), (9) and (10) was used to estimate these parameters [9, 12 - 18].

$$Zpos = Rac + j2w10^4 \text{ x In} \left(\frac{DP}{GMR\ 1}\right) \text{perkm} \quad (3)$$

$$Zzero = Rac + 1.5w10^4 + j6w\,10^4 \text{ x In}(659 \left(\frac{F}{p}\right) 1/3(GMRI \times ((DP^2)^{\frac{1}{3}}) \quad (4)$$

Where,

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

$$Rdc = \rho l/A \text{ ohms} \quad (5)$$

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} = 1.1Rdc (6)

C_{pos} = 2Π€$_o$[1/In(DP/RD1)] seimen/km (7)

C_{zero}= 2Π€o/ In[$(2H)^3$/(RD1 x DP^2)] seimen/km (8)

The value of €o is negligible and as such it may not be substituted for the calculation of C_{pos} and C_{zero} in equations (7) and (8) respectively. H1, H2 and H3 are the heights of the three phase conductors from the ground while DP_{12}, DP_{23} and DP_{13} are the spacing between the phases. Therefore, equivalent H (G.M.H) and equivalent DP (G. M. DP) can be evaluated using equations (8a) and (8b) as follows [14];

G. M. H = $(H_1 \times H_2 \times H_3)^{1/3}$ (8a)

G. M. DP = $(DP_{12} \times DP_{23} \times DP)^{1/3}$ (8b)

Propagation constant is the change occurring in the transmitted waves as it propagates along the line. Propagation constant (Q) consists of the real part called the attenuation constant and the imaginary part called the angular phase shift as represented by equation (9);

Q = A + jb

= $((R + jwl) (G + jwc))^{0.5}$ = $(Z \times Y)^{1/2}$ (9)

Characteristic impedance (Zc) is the input impedance of an infinite length of the line, i.e if any line is terminated, its input impedance is the same as the characteristic impedance as represented by equation (10);

Zc = $((R + jwl) / (G + jwc))^{0.5}$ = (Z/Y)1/2 (10)

For a lossless line (i.e R = 0, G = 0), the characteristic impedance is referred to as the surge impedance and represented by equation (11) [14]

$Z_0 = (L/C)^{0.5}$ (11)

Furthermore, since power transmission line carries voltage (V) at a specified current (I) depending on the size of conductor used, then it becomes possible to calculate the three-phase power of the line carried by a tower structure using equation (12) [9, 12, 15, 17];

S =$\sqrt{3}\, VIcos\theta$ (12)

Where,

S= Apparent power on the line.

Cosθ =Power factor of the transmission network

In this paper, a structured transmission tower was used to generate the symmetrical component parameters of the installed tower at different locations of varying Earth resistivity values shown in Table 1[14, 16, 17].Other parameters required in this analysis regardless of the Tower structure are presented in table 2 to 4. The voltage and current rating on the line are specified as 330kV and 1330A respectively.

Table- I: Earth (Ground) Resistivity values

No	Nature of ground	Earth (Ground) Resistivity (GR)in meter ohms (B)
1.	Sea water	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

Table- II: ACSR conductor specifications

COND. SIZE (mm^2	AL. STR (No.)	AL. DIA (mm)	SL. STR (No.)	SL. DIA (mm)
150	26	2.7	7	2.1
700	100	6	14	6
764	108	6	14	6
764	108	6	14	6

Table- III: Conductor parameters

COND. SIZE (mm^2	AC RESIST. (ohm/km)	GMR (meter)	RD (meter)
150	0.20753	0.00538	0.00691
700	0.04447	0.011607	0.01493
764	0.04075	0.012145	0.01559
764	0.04075	0.012145	0.01559

Table- IV: Conductor sizes and power ratings

COND. SIZE (mm^2)	STD. LENGTH (meter)	CURRENT RATINGS (A)	VOLTAGE RATINGS (kV)
150	3000	393.6	132
700	760	1330	330
764	750	1466	500
764	750	1466	700

III. METHODOLOGY

1. Obtain transmission tower structure with known Earth resistivity of the ground on which the tower is erected.
2. Decide the conductor bundling level per phase of the chosen transmission tower (i.e 2, 3, 4, 5 bundle etc.)
3. Obtain input data of the chosen conductor such as conductor size, radius, geometric mean radius, voltage rating, current rating etc.
4. Develop a computer software program(Python) to evaluate the transmission line symmetrical component parameters using the following algorithm:
   a) Start
   b) Equivalent GMR (GMR(I)) of the Conductor using equation (1)
   c) Equivalent Radius (RD(I)) of the Conductor using equation (2)
   d) Alternating current resistance R_{ac} of the line using equation (6)
   e) Equivalent height (H) of the 3-phase conductors from ground and the equivalent spacing (DP) between the 3-phase using equation (8a) and (8b) respectively.
   f) $C_{positive}$ and C_{zero} using equation (7) and (8) respectively.
   g) Set a counter B(I)=1; for Tower Earth Resistivity in consideration.
   h) $Z_{positive}$ and Z_{zero} using equation (3) and (4) respectively.
   i) Propagation constant (Q) and Characteristic Impedance (Zc), using equation (9) and (10) respectively.
   j) Apparent power at the transmission tower using equation (12).
   k) Is B(I) = T, where T is the maximum number of transmission tower earth resistivity in consideration (i.e., T = 6)?
   l) If No, then I = I +1, then GOTO 4(g) above.
   m) If yes, GO TO 4(n).
   n) Print results (i.e Symmetrical component Parameters) for all B(I) i.e for all tower earth resistivities considered.
   o) End

IV. RESULTS OF THE ANALYSIS

The results of the symmetrical component parameters' analysis for lines on a tower support using the methodology described above are presented as follows. These results are for six tower structures but installed on different grounds (or earth) resistivity (GR) values ranging from 0.1 to 10^8 mΩ. Summary of the data used in the analysis are briefly presented as follows:

Number of Sub-Conductors making up a phase bundle = 2
Number of Transmission tower to be studied = 1
Power Generation Frequency= 50 Hz
Division Factor for Bundle Sub-Conductor Distance = 25
Number of Earth Resistivity considered = 6

Calculated Bundled Conductors' Parameters:

G.M.H = 24.456 m
G.M.DP = 11.56291 m
BUNDLE COND. DIST = 0.46252 m

Calculated Equivalent Parameters for the Tower

EQUIV. RADIUS = 0.08308 m
EQUIV. G.M.R = 0.07326 m

Line capacitive suceptances in terms of the symmetrical components C_o, C_1 and C_2.

C(ZERO) = 0.57235
C(POSITIVE) = 0.94465
C(NEGATIVE) = 0.94465

Table- V: Line impedances in terms of the symmetrical components Z_o and Z_1

Tower Earth Resistivity	Z_I(ZERO)	Z_{II}(ZERO)	Z_I(POS)	Z_{II}(POS)
0.1	0.00083	2.65878	0.02594	0.49890
50	0.00083	2.65878	0.02594	0.49890
10^3	0.00083	1.77293	0.02594	0.49890
10^7	0.00083	-0.95061	0.02594	0.49890
10^8	0.00083	-1.6315	0.02594	0.49890
10^2	0.00083	2.45381	0.02594	0.49890

Table- VI: Impedance in magnitude and phase form.

Tower Earth Resistivity	Z_0(MAG)	Z_1(MAG)	PHASE ANG.$_0$(Degree)	PHASE ANG.$_1$(Degree)
0.1	1.63057	0.7068	182925.56	1101.83
50	1.63057	0.7068	182925.56	1101.83
10^3	1.63057	0.7068	182925.56	1101.83
10^7	0.97499	0.7068	-65402.74	1101.83
10^8	1.27730	0.7068	-112248.03	1101.83
10^2	1.56646	0.7068	168823.72	1101.83

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Table- VII: Propagation constants in complex form.

Tower Earth Resistivity	Q_1 ZERO	Q_{11}ZERO	Q_1 POS	Q_{11}POS
0.1	4.76586E-4	1.52177	0.02450	0.47129
50	4.76586E-4	1.52177	0.02450	0.47129
10^3	4.76586E-4	1.01474	0.02450	0.47129
10^7	4.76586E-4	-0.54409	0.02450	0.47129
10^8	4.76586E-4	-0.93380	0.02450	0.47129
10^2	4.76586E-4	1.40445	0.02450	0.47129

Table- VIII: Propagation constants in magnitude and phase.

Tower Earth Resistivity	Q_0(MAG)	Q_1(MAG)	PHASE ANG.0 (Degree)	PHASE ANG.1 (Degree)
0.1	1.23360	0.68697	182925.56	1101.83
50	1.23360	0.68697	182925.56	1101.83
10^3	1.00734	0.68697	121978.43	1101.83
10^7	0.73762	0.68697	-65402.74	1101.83
10^8	0.96633	0.68697	-112248.03	1101.83
10^2	1.18509	0.68697	168823.72	1101.83

Table- IX: Characteristic impedances in complex form.

Tower Earth Resistivity	Z_{C1}(ZERO)	Zc_{11}(ZERO)	Z_{C1}(POS)	Zc_{11}(POS)
0.1	0.00145	4.64532	0.02745	0.52813
50	0.00145	4.64532	0.02745	0.52813
10^3	0.00145	3.09759	0.02745	0.52813
10^7	0.00145	-1.66087	0.02745	0.52813
10^8	0.00145	-2.85049	0.02745	0.52813
10^2	0.00145	4.28721	0.02745	0.52813

Table- X: Characteristic impedance in magnitude and phasor form.

Tower Earth Resistivity	ZC_0 (ZERO)	ZC_1 POSITIVE	PHASE ANG.$_0$ (Degree)	PHASE ANG.$_1$ (Degree)
0.1	2.15530	0.72722	182925.56	1101.83
50	2.15530	0.72722	182925.56	1101.83
10^3	1.75999	0.72722	121978.43	1101.83
10^7	1.28875	0.72722	-65402.74	1101.83
10^8	1.68834	0.72722	-112248.03	1101.83
10^2	2.07055	0.72722	168823.72	1101.83

V. DISCUSSION OF RESULTS

The configuration of the tower shown in Figure 1 is used to estimate the value of the Geometric Mean Height (GMH), Geometric Mean Distance between phases (G. M. DP), Bundle conductor distances, Conductor radius and Geometric Means Radius of conductors as well as the apparent power. With the knowledge of the current and the voltage rating of the lines on this tower in consideration, the power rating estimation vividly depends on the conductor cable size and the voltage to be transmitted. It is quite understood that conductor size of the cable increases alongside the voltage that needs to be transmitted, thus, the power rating also increases.

The results on Table 5 shows the line impedances in terms of the symmetrical components Zo, Z_1 and Z_2 where each of them is expressed as real and imaginary components. Table 5 shows that the values of Z_1(ZERO), Z_1(POSITIVE), Z_{11}(POSITIVE) remains unchanged irrespective of the value of the earth resistivity, while Z_{11}(ZERO) which are the imaginary values of Zero sequence impedance significantly responded to variation in values of earth resistivity. Also, in Table 6, the positive sequence impedance magnitude, Z_1(MAG) respond to higher values of earth resistivity while the corresponding PHASE ANG_1 remain unchanged. The zero-sequence magnitude of impedance, Z_0(MAG), partially response to higher values of earth resistivity. The corresponding PHASE ANG $_0$responded significantly to increased values of earth resistivity. Although, some of these values are negatives.

Propagation constant and characteristic impedance are each a function of impedance as illustrated in equations (9) and (10) respectively. Table 7 shows the Propagation constants in complex form where the values Q_1(ZERO), Q_1(POS) and Q_{11}(POS) remain unchanged irrespective of the value of earth resistivity. Q_{11}(ZERO)which is the imaginary part of zero sequence propagation constant responded to variation in earth resistivity, while the real parts , Q1 zero, are constants having high negative exponential values, implying about zero values or negligible values.

In table 8, the magnitude of zero sequence propagation constants, Q_0 (MAG) varies with changes in earth resistivity while the magnitude of positive sequence of propagation constant Q_1 (MAG)remains the same value irrespective of the value of earth resistivity. The zero-sequence phase angle, PHASE $ANG._0$ of the propagation constant responded to earth resistivity. This result is observed to be the same with the values obtained for zero sequence phase angle of impedance. This confirms that the propagation constant is a function of impedance.

Table 9 shows the characteristic Impedances in complex form**.** The values of ZC1 (ZERO), Z_{C1}(POS) and Z_{C11} (POS) does not change with variation in earth resistivity while the value of Z_{C11}(ZERO) changes in value with increased earth resistivity. Also, Table 10 further illustrates the magnitude of characteristic impedance and phase angle as $Z_{C\ 1}$(POS) and PHASE $ANGLE_1$ which remain unchanged irrespective of the earth resistivity value while the Z_C (ZERO) and PHASE $ANGLE._0$changes with variation in the values of the earth resistivity.

VI. CONCLUSION

Symmetrical parameters of lines on tower evaluated gave the standard requirements for the effective performance of tower of such structures. It was observed that tower configuration structure as well as resistivity of the ground on which the tower is located are the most important data required in calculations and it varied from one tower to the other. The increased values of the positive sequence resistance on lines due to ground wires that are often grounded at every tower is of practical importance. This increase reflected the losses caused by the circulating currents in the ground wire. However, it is important to state that line parameters at higher frequencies are required for switching and lighting surge studies. This becomes necessary for power line carrier studies and similar problems

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