

PROPAGATION CHARACTERISTICS OF THE VERTICAL CONFIGURATION OVERHEAD 132KV SINGLE CIRCUIT POWERLINES

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Abstract

High voltage powerlines can also be used for intelligence transmission. Before this can be done, the propagation behaviour of the lines needs to be known. The paper considers the vertical configuration type single circuit (SC) overhead powerlines of the Power Holding Company of Nigeria (PHCN) for transmission of intelligence. Some lines data were collected from the PHCN Headquarters from which the basic admittance matrix and impedance matrix were derived and used to obtain the high frequency parameters. These parameters reveal the propagation characteristics of the lines. The effects of the load cycle were also studied by considering the meteorological conditions of the regions the lines are run. The loading effects on the lines given the peculiar atmospheric conditions in these zones were studied. The results obtained were discussed and conclusions drawn.

Keywords: Load cycle, powerline carrier, propagation

1. Introduction

Since the advent of electrical power distribution networks, the need for intelligence transfer over power lines has become desirable. It is economically advantageous to use the lines themselves to enhance supervisory and control operations, provide fast information dispatch and to carry out discriminative protection of substation equipment by sending trip signals when faults occur. These important tasks can be achieved by using the power line carrier (PLC), which describes the significant use of carrier current communication when utilising the high voltage transmission line.

Several works on PLCs have been done on various installations. In some cases, studies are made and findings therefrom documented while in other cases, methods of analysis and computations are presented and applied to some existing practical systems. Some of these documentations include that of Godfrey [1], who discussed the use of power distribution lines as communications medium, which is proven to be a reliable, cost effective alternative to dedicated lines.

In London, following the privatisation of electricity, gas and water which led to the development of communication systems to provide automatic meter reading (AMR), price tariffs and load management, Newbury [2] discovered that the poor signal conditions over the low voltage mains network due to signal attenuation leading to low SNRs and consequent reduced propagation conditions require specific transmission and reception conditions over the power line. Effective communication is achieved including the effects of the loads on the line due to the switching on and off of electrical appliances. Gabel [3] suggests the use of the German's electricity supply mains as carriers of

signals in the region of 90 to 131kHz suitably modulated for speech transmission and remote control of household electrical equipment.

PLC studies and analyses have also been extended to direct current (dc) transmission systems as well as other useful applications. Ainsworth [4] observed that two (or more) terminals of a high voltage direct current (HVDC) link normally requires interconnections via a telecommunication system. His work deals primarily with the control and supervisory signals and discusses the requirements from the dc point of view; the possible telecommunication channels and the interfaces to these, including the master controls and the general system behaviour. Halme [5] stressed the need for investments in data networks due to the advanced automation applied in the transmission and distribution of electric power.

Very recent researches have, in addition recognized the use of electricity lines as data transmission medium. For instance, Adam [6] examines plans to use the national grid to transmit data. In this line, the Internet news reported that Nortel (Northern Telecommunications) and Norweb of UK signed an agreement to exploit the potential of the national electricity grid for transmitting data.

John [7] reported a recent interest of data transmission via power lines on the German energy conglomerate Veba, working with U.S. home networking firm Enikia, which is close to launching a service offering high – speed Internet access over power lines. Under the auspices of a new communications company dubbed Online AG, the service was scheduled to go into European market trials during the year 2000 summer, with a full

commercial release by the end of that year. The company also hopes to launch a trial project in the United States.

Adegboye [8] applied the modal analysis and methods of studying the effects of various cycles on transmission lines to a model of the 330kV single circuit NEPA transmission lines for the purpose of determining the data transmission potentials of such lines. The work was previously carried out [9] on the triangular configuration of the SC 132kV transmission lines. The 330kV transmission line model was found to exhibit better transmission potentials.

In the present paper, analyses and studies are conducted on the Nigeria's single circuit 132kV vertical configuration overhead powerlines. The analyses carried out are based on travelling-wave phenomena [10]. The application of this method is extensively described in references [9, 11, 12]. The effects of load current on the transmission line parameters [13, 14] are also considered.

2. Meteorology Conditions

The country's climate is essentially tropical (Source: NEPA Document EED/230.143 L, July 1988, section 1.09). The features are briefly described.

Temperature

Average maximum (hot season): 30°C (Zone A);

40°C (Zone B)

Average minimum (cold season): 23°C (Zone A);

11°C (Zone B)

Generally, minimum temperature: 10°C; maximum

temperature: 75°C

Country's average maximum: 35°C

Average daily minimum: 17°C

Wind

Average wind speed: 112km/h or 31.11m/s (Zone A);

192km/h or 53.33m/s (Zone B)

Average nominal wind speed: 64km/h or 17.78m/s

Wind pressure on projected area of line and earth

conductors and insulator sets: 575N/m² (Zone A);

952.8N/m² (Zone B)

3. Line Conductors and Earth Wire

Specifications

The line conductors are the Aluminium Conductor Steel Reinforced (ACSR) type. A model of the 132kV SC transmission lines (model_1) having all the phase conductors on the left side of the tower and one earth wire on the tower axis is investigated. This is shown in Fig.1. The tower axis is taken as the

reference axis. All dimensions are in metres (m). Table 1 summarises the line parameters.

TABLE 1: Line parameters

Parameter	Conductor	Earth wire
Resistivity ($\times 10^{-8} \Omega\text{m}$)	3.82	20
Diameter (mm)	23.45	9.8
Diameter of one Aluminium strand (mm)	3.35	
Diameter of one strand		3.25
Diameter of one Steel strand (mm)	3.35	
Number of Aluminium strands (mm)	30	
Number of Steel strands (mm)	7	
Number of strands		7
Resistance per unit length ($\times 10^{-3} \Omega$ at 20°C)	0.1095	3.442

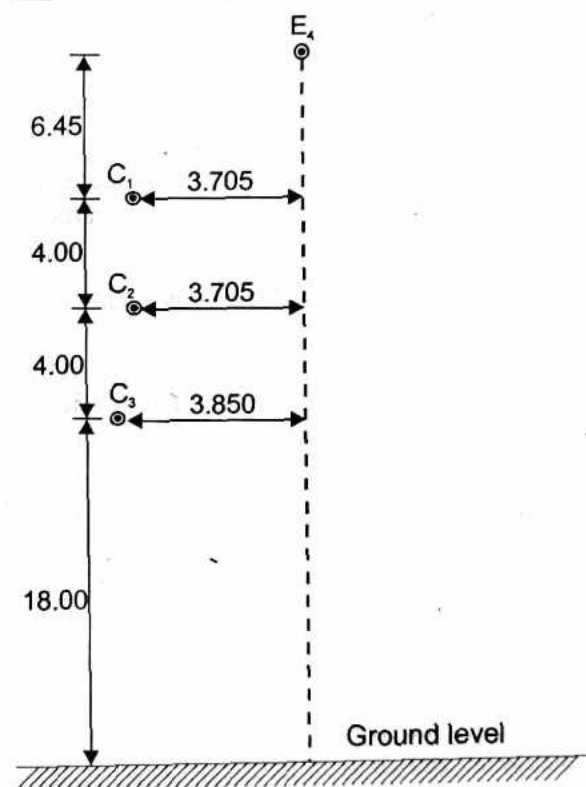


Fig. 6.1: Model_1

3.1 Other Constants

In general, the following constants are assumed, as appropriate, in the relevant areas of the computations:

- resistance temperature coefficient: 0.0004 for most alloys;
- solar absorption coefficient: 0.175;
- solar constant: 1376Wm⁻² [15]
- thermal emissivity: 0.0615;
- Stefan's constant: 5.669 $\times 10^{-8}$ Wm⁻²K⁻⁴;
- Thermal coefficient of linear expansion: 17.8 $\times 10^{-6}$ /°C (see EED/ 230.143L).

3.2 Line geometry

The co-ordinates of the conductors are obtained from Fig.1. All dimensions are in metres (m). The co-ordinates of the conductors in each mode and the conductors' geometry are shown in Table 2 and Table 3, respectively.

TABLE 2: Mode co-ordinates

	Model 1
Mode 1	(-3.705, 26.0)
Mode 2	(-3.705, 22.0)
Mode 3	(-3.850, 18.0)

TABLE 3: Conductor geometry co-ordinates

	Model 1
Position 1	(-3.705, 26.0)
Position 2	(-3.705, 22.0)
Position 3	(-3.850, 18.0)
Position 4	(0.0, 32.45)

4. Results

This section presents the results involving parameters at high frequencies because they reveal the propagation characteristics of the transmission lines. The effects of the various loading parameters of the lines are also presented.

4.1 Basic Matrices and High Frequency Parameters

The basic matrices and high frequency parameters are obtained for different frequency values. The high frequency parameters are the mode distribution vectors (voltages and currents), the mode propagation constants (attenuation and phase), the characteristic impedance and the characteristic admittance. In this paper, however, the 100kHz parameters are presented.

The basic admittance and impedance matrices, mode distribution vectors and mode propagation parameters corresponding to 100kHz frequency are shown in

Tables 4 through 6.

TABLE 4: 100kHz frequency Y and Z parameters

Parameter	100kHz
Admittance matrix, S	1.0e-005 *
	0.4861i - 0.1186i - 0.0693i
	- 0.1132i 0.5045i - 0.1184i
	- 0.0582i - 0.1113i 0.4909i
Impedance matrix, Ω	0.6771+ 7.0446i 0.6357+ 2.5126i 0.5966+ 2.0193i
	0.7715+ 2.5775i 0.9345+ 7.3235i 0.8543+ 2.7336i
	0.8739+ 2.1536i 1.0636+ 2.8512i 1.2728+ 7.6094i

TABLE 5: Mode voltages and currents at 100kHz

Mode	Voltage	Current
1	0.4039- 0.0007i	0.5095+ 0.0180i
	0.5540+ 0.0068i	0.5653+ 0.0077i
	0.7277+ 0.0163i	0.6609+ 0.0037i

2	-0.5657- 0.0246i	-0.7763- 0.0294i
	-0.3570- 0.0217i	-0.2604- 0.0008i
	0.7423+ 0.0221i	0.6284+ 0.0293i
3	0.5101- 0.0221i	0.6929- 0.0402i
	-0.8057+ 0.0470i	-0.7348+ 0.0367i
	0.2961- 0.0170i	0.1747- 0.0092i

TABLE 6: Propagation vectors at 100kHz

Mode	Attenuation 1.0e-003 *	Velocity 1.0e+008 *
1	0.6417	1.0320
2	0.1067	1.1708
3	0.0469	1.1851

Characteristic Impedance Matrix, Ω
1.0e+003 *

1.2625- 0.0570i 0.4039- 0.0523i 0.3141- 0.0484i
0.4008- 0.0634i 1.2884- 0.0776i 0.4228- 0.0697i
0.3078- 0.0704i 0.4221- 0.0865i 1.3077- 0.1055i

Characteristic Admittance Matrix, Ω
1.0e+003 *

1.1101- 0.0225i 4.2076- 0.1080i 7.1037- 0.1490i
4.2057- 0.2224i 1.0764- 0.0260i 4.0618- 0.1752i
7.1653- 0.6879i 4.0189- 0.3260i 1.1430- 0.0556i

4.2 Effects of Load Cycle

The effects of load variations on some transmission line parameters such as conductor temperature, tension, sag, effective height and length (including the total line length) are considered. These are shown in Tables 7 through 9.

TABLE 7: Seasonal temperature rise at each zone

Load (A)	Hot Season Temperature ($^{\circ}\text{C}$)		Cold Season Temperature ($^{\circ}\text{C}$)	
	Zone A	Zone B	Zone A	Zone B
50	199.6650	179.9783	213.5710	237.3475
100	230.2270	207.3938	246.3742	274.0166
150	282.7134	254.3354	302.8293	337.3556
200	359.6395	322.8145	385.8471	431.0296
250	464.9527	415.9514	500.0329	560.9206
300	604.5794	38.3559	652.3811	736.1405
350	787.3563	96.7580	853.4798	970.8519
400	1026.6	901.0648	1119.7	1287.7
450	1.343.3	1166.2	1477.1	1724.4
500	1771.3	1515.4	1969.7	2349.0
550	2369.7	1986.9	2677.6	3295.3
600	3250.5	2647.4	3762.3	4869.2

650	4654.2	3625.1	5605.1	7952.0
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TABLE 8: New seasonal tension at each zone

Load (A)	Hot Season Tension (N)		Cold Season Tension (N)	
	Zone A	Zone B	Zone A	Zone B
50	67216.1	98032.6	64992.8	85380.8
100	62599.3	91332.1	60514.5	79467.7
150	56493.7	82482.6	54585.9	71624.9
200	50091.0	73219.4	48360.4	63369.2
250	44055.8	64507.1	42482.6	55551.7
300	38635.8	56703.7	37193.5	48493.0
350	33635.8	49844.4	32518.2	42226.9
400	29650.0	43831.5	28390.6	36666.0
450	25920.3	38528.5	24718.5	31685.0
500	22572.6	33799.3	21405.7	27147.7
550	19515.6	29517.9	18359.3	22920.7
600	16663.0	25572.0	15488.3	18855.9
650	13925.4	21853.2	12689.3	14754.9

TABLE 9: Sag, effective height and length during cold season in zone B

Load (A)	Sag (m)	h_{em} (m)	h_{em} (m)	h_{em} (m)	l_{em} (m)	l_{em} (m)
50	0.3906	25.7396	21.7396	17.7396	280.0015	560.0029
100	0.4196	25.7202	21.7202	17.7202	280.0017	560.0034
150	0.4656	25.6896	21.6896	17.6896	280.0021	560.0042
200	0.5262	25.6492	21.6492	17.6492	280.0026	560.0052
250	0.6003	25.5998	21.5998	17.5998	280.0034	560.0068
300	0.6877	25.5415	21.5415	17.5415	280.0045	560.0090
350	0.7897	25.4735	21.4735	17.4735	280.0060	560.0119
400	0.9095	25.3937	21.3937	17.3937	280.0079	560.0157
450	1.0525	25.2983	21.2983	17.2983	280.0106	560.0211
500	1.2284	25.1811	21.1811	17.1811	280.0144	560.0287
550	1.4549	25.0301	21.0301	17.0301	280.0202	560.0403
600	1.7686	24.8010	20.8010	16.8010	280.0298	560.0596
650	2.2601	24.4933	20.4933	16.4933	280.0486	560.0973

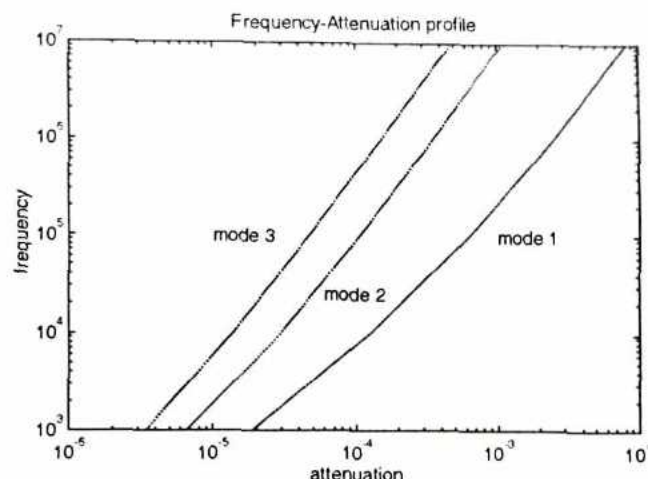
5. Discussion of Results

At high frequencies, Y reduces by factor 10 when the frequency is increased by the same factor. However, the magnitude of Z increases with increasing values of frequencies.

5.1 Propagation Characteristics

5.1.1 Attenuation

The variations of attenuation with frequency for the three modes are shown in the frequency – attenuation profile of Fig.2.



At each level of frequency, modes 2 and 3 are associated with lower attenuation. As can be observed, mode 3 at 1kHz frequency has the lowest attenuation while mode 1 at 10MHz frequency has the highest attenuation.

5.1.2 Velocity

The variations of propagation velocity with frequency for the three modes are shown in the frequency – velocity profile shown in Fig.3.

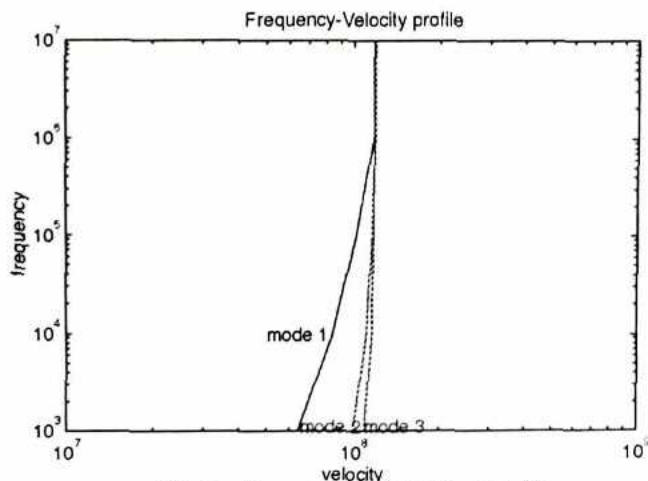


Fig.3: Frequency-Velocity Profile

It can be observed that mode 3 at 1MHz and 10MHz frequencies propagates at the highest velocities while mode 1 at 1kHz frequency propagates at the lowest velocity.

5.1.3 Propagation

The mode of propagation, which is characterised with the least attenuation and the highest velocity, is considered most suitable. Therefore, the velocities and attenuations values were closely observed to get the acceptable modes of propagation. The following results were obtained:

- 1 Mode 3 at 1kHz frequency – excellent 1
- 2 Mode 2 at 1kHz frequency – excellent 2

- 3 Mode 3 at 10kHz frequency – very good 1
- 4 Mode 2 at 10kHz frequency – very good 2
- 5 Mode 3 at 100kHz frequency – very good 3
- 6 Mode 2 at 100kHz frequency – good 1
- 7 Mode 3 at 1MHz frequency – good 2
- 8 Mode 2 at 1MHz frequency – good 3
- 9 Mode 3 at 10MHz frequency – good 4
- 10 Mode 1 at 100kHz frequency – good 5

As can be seen, modes 2 and 3 are the prominent modes (aerial modes); mode 1 surfaced only once and this is the least acceptable mode of propagation.

5.2 Load Cycle Variations

5.2.1 Temperature

The temperature – load profiles of the lines run in the two zones are shown in Fig.4 during the hot season. These profiles show that increase in load gives a corresponding increase in temperature. They also show that the conductor temperature in the hot season is higher in zone A than in zone B even though the zone A weather is generally cooler than that of zone B during hot seasons. The converse is also true. This is due to the fact that in zone B, the wind speed is much higher than that in zone A; therefore, the heat loss due to convection will be higher.

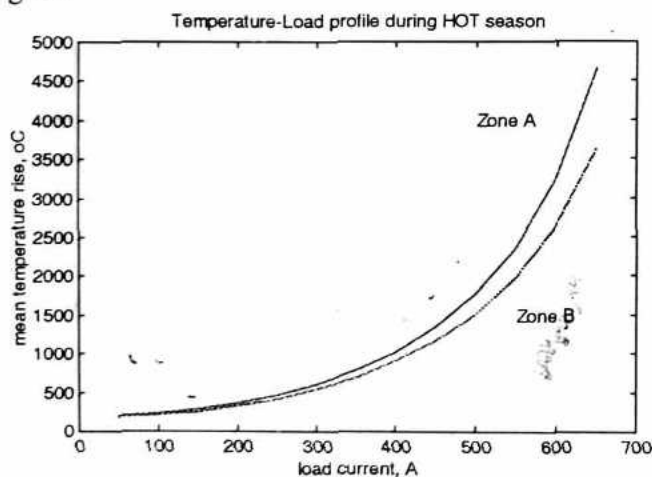


Fig.4: Temperature-Load profile during HOT season

The contribution of other components like the heat due to radiation and line current considers the ambient temperature. Meanwhile, the heat due to solar radiation is common to the two zones.

5.2.2 Tension, Sag and Effective Height

The prescribed tension limit of the line conductors is 31kN. During the cold season, for example, the maximum safe tension that does not exceed the prescribed limit is 28.39kN at a loading of

400A in zone A (see Fig.5). This tension gives sag of 0.8481m. As a result of the sags, conductor heights generally reduce. The extensions experienced by the lines are insignificant when compared to the line length. Attenuation does not vary much with load current except when the load current lies around the critical frequency. This critical frequency was calculated as 4kHz along the Zaria – Kaduna line whose line length is 72km during the propagation of the aerial modes at 1kHz.

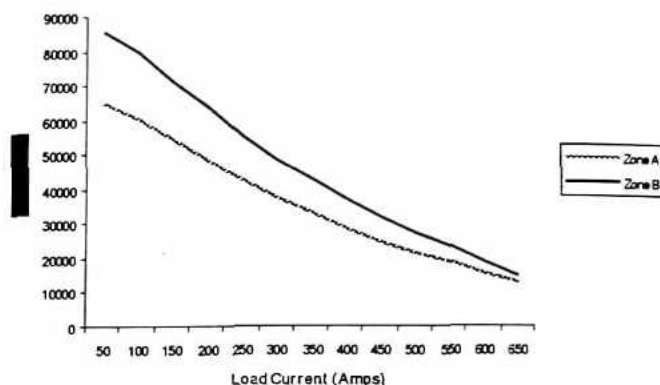


Fig. 5: Tensions corresponding to load currents in the cold season for model_1

6. Conclusions

The paper had set out to the following:

- To characterise the attenuations and propagation velocities on the PHCN 132kV SC vertical configuration powerlines; and
- To identify the propagation modes at which significant power would be obtained at the receiving end;
- To study the effect of load variations on the powerlines.

In line with the above objectives, the following conclusions are hereby drawn:

1. Modes 2 and 3 are the aerial modes, although modes 2 are generally associated with more losses than modes 3 at each frequency level;
2. Mode 3 at 1kHz enjoys the least attenuation while mode 1 at 10MHz suffers the greatest attenuation;
3. Mode 3 at 1MHz and 10 MHz propagates at the highest velocity while mode 1 at 1kHz has the lowest propagation velocity;
4. The best propagation behaviour is achieved within 1kHz and 100kHz and to some extent up to 1MHz;
5. Modes 1 generally have the highest attenuation at each frequency level and utilize the ground path for return;

6. The propagation velocities are the same for all modes from the frequency of 10MHz down to 1MHz and fairly coincide for the aerial modes only when there is further drop in frequency to a value close to 100kHz (about 133kHz);
7. The mean propagation velocity of the aerial mode is 38.39% of that of free space value and is 31.84% for the earth-return mode. This means that propagation, even in the best modes, is very slow;
8. In the two seasons and zones, an increase in the load current is accompanied by a non-linear increase in the ambient temperature rise;
9. Conductor temperature rise in the hot season is higher in the zone A than in the zone B;
10. Transmission line loading for the minimum safe tension is usually higher in zone B irrespective of the meteorological condition;
11. Depending on the season, transmission line loading directly affects the conductor temperature, the rise of which increases the line length and reduction in tension;
12. Increase in conductor temperature due to loading causes an increase in line length and increase in sag;
13. Sags increase with increase of line current and are generally higher than the line extensions;
14. The effective height of the transmission line is lower than its actual (designed) height due to sag; this difference, however, causes a corresponding change in the aerial modes velocities;
15. There is almost no variation of attenuation with load current within a zone around the critical frequency where the variation is rapid;
16. The effective height of conductor decreases with increase in sag and affects the carrier attenuation.

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