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Characterization and Analysis of A Healthy 330 Kilovolt Double Circuit Transmission Line

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***Abstract* - A 330KV healthy transmission line was analyzed with the aim to investigating the influence of high voltage on human being at normal regime. Some of the operating parameters of the line, namely: shock current and voltage, inductance, reactance, radio interference, electric field charge and corona effect were highlighted. The level of protection of humans and safety operation of the power system were investigated using numerical analysis. From the analysis, a healthy 330KV transmission line can generate a carrier frequency of about 85 KHz and that corona formation in double circuit power lines is slower than in single circuit lines and that step voltage is proportional to transmission line sag. Based on the results of the paper, normally operating 330KV transmission line parameters do exceed their rated values and this is not good for healthy living.**

***Keywords* - V_{cont} = Contact voltage, V_s = Step voltage, F_c = Carrier Frequency, q = Electric field intensity of power lines, GMD – Geometric mean distance among the three lines.**

I. Introduction

330 KV is classified as high voltage and it is usually seen passing through major cities of the Country. Apart from supplying voltage and power over long distances, 330 KV line also supplies carrier frequency. The operation of 330 KV transmission lines has been improved in the recent time with the introduction of double circuited ring lines. By this, the active, reactive and corona losses have been halved throwing to a higher level the efficiency of transmission lines in today's ever increasing demand for electricity supply.

The paper is looking at the object of a healthy 330 KV transmission line with a view to analyzing it. The centre of interest is the security, safety and harmless operation of a high voltage transmission line in the environment of human cohabitation. The parameters that draw attention in this regard are the electromagnetic radiation oozing out of a healthy transmission line, the radio interference, the corona loss, and the contact and step voltage. Empirical analysis shows that the reactance of high voltage transmission lines plays the most important role in ensuring the reduction of shock voltage and current.

The capacitance of a healthy power line is a function of the height of conductor with respect to the bare ground. The high electric charge (q) gotten from the calculation shows the adverse effect of high density of the air mass. From the analysis, it was obvious that the capacitive voltage of the power line under consideration is V_c = 237.15 Volts at half the distance between two lines. If the ground resistance is zero, then humans are standing under such high voltage lines at the mercy of their internal resistance and the density of the air mass. Lastly, the transmission line was tested on corona loss and it gave positive response. It should also be noted that the losses encountered in the transmission lines are burnt up as heat which also constitutes global warming.

Parameters of the 330 KV double circuit power line

Length of transmission line = 600Km
Type of conductor = ASCR (Aluminium Conductor Steel Reinforced)
Size of conductor = 400/18 mm^2 with current capacity of 825A [1]
Rated power P = 450 Mw/line
Frequency f = 50Hz
Cosφ = 0.92

II. Normal Capacitive Current of a Healthy 330 KV Line

The capacitance C of the air mass between the current-carrying conductor and the ground can be measured instrumentally or by calculation as follows:

$C = \varepsilon_r*\varepsilon_o*GMD/d = 1.0*8.854*10^{-12} * 8.505m/24.7m = 3.05*10^{-12}$ Farad, where $GMD = \sqrt{(D_1*D_2*2*D_3)} = \sqrt{(6.75*6.75*2*6.75)} = 8.505m$. GMD = geometrical mean distance between transmission lines. It can also be approximated as GMD = 1.26*D for a 3-Phase circuit, ε_r = permeability of air, ε = permeability of vacuum, D = distance bzetween lines, d = vertical distance between ground and the conductor [5]. The reactance of the power line relative to the ground X_c is defined as:

$X_c = 1/2\pi*f*C = 1/2\pi*50*3.05*10^{-12} = 1.044*10^9$ ohms

The corresponding capacitive current I_c is:

$I_c = V/X_c = 330*10^3/1.044*10^9 = 0.316$ mA

Maximum voltage and current allowed for human contact during normal a.c. system regime at 50 Hz is 2Volts and 0.30 mA respectively [6].

III. Calculation of Carrier Frequency

The equivalent radius of the double circuit line is

$R_{eq} = \sqrt{R_o*a} = \sqrt{11.28*300} = 58.17$mm [5].

where $R_o = \sqrt{A/\pi} = \sqrt{400/\pi} = 11.28$mm (radius of conductor), *a* = distance between conductors of the same line (300mm assumed). For a two conductor bundle $GMR_b = \sqrt{dGMR_c} = \sqrt{2*0.7788*R_o*R_{eq}} = \sqrt{2*0.7788*11.28*58.17} = 31.97$mm. Therefore, the inductance of the conductor can be defined as:

$L_o=L_a=L_b=L_c=*10^{-7}\ln(GMD/GMR_b)=2*10^{-7}* \ln(8.505/31.97*10^{-3}) = 1.12*10^{-6}$ Henry [7].

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The capacitive reactance of the double circuit line is: C_o = $7.58*10^{-6}/\log(GMD/GMR_b)=7.58*10^{-6}$ $/\log(8.505/31.97*10^{-3})$ = $3.125*10^{-6}$ Farad.

The carrier frequency of the 330KV transmission line is facilitated by two parameters, namely: the capacitance C_o and the inductance L_o and it is defined as Fc = $1/(2\pi\sqrt{L_o * C_o})$= $1/(2\pi\sqrt{1.12*10^{-6}*3.125*10^{-6}})$ = 85071.9Hz.

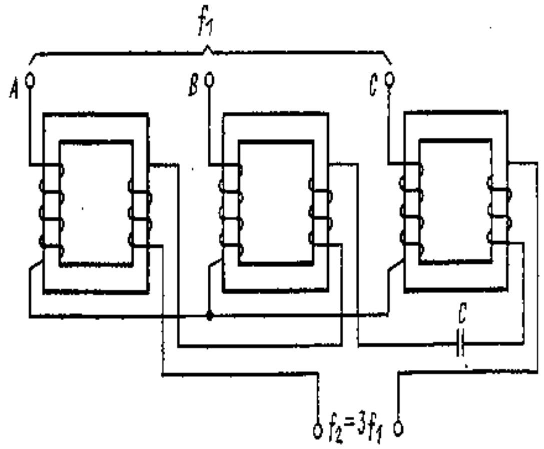

Fig.1. Frequency Tripler

The carrier frequency can be converted to useful purposes by incorporating a frequency Tripler (booster) as depicted in Fig. 1.0 to amplify the frequency [8]. Therefore, the frequency can be raised as high as 255.05 KHz which is in the range of a long wave band. Increasing the equivalent radius of the double circuit line Req will facilitate the increase of the carrier frequency, but this will not be economically viable because of conductor over weight and unacceptable sag. It will also increase the right of way requirement for the 330KV circuit. In Fig. 1.0, the points

A, B, and C are high voltage terminals to the step down core transformer, f_1 = input system frequency from carrier signals (85071.9 Hz), f_2 = output frequency and C = fixed A, B, and C are high voltage terminals to the step down core transformer, f_1 = input system frequency from carrier signals (85071.9 Hz), f_2 = output frequency and C = fixed core transformer, f_1 = input system frequency from carrier signals (85071.9 Hz), f_2 = output frequency and C = fixed capacitor. The carrier frequency tends to disappear on the low voltage winding of step down transformers unless recreated artificially, and so exerts no adverse influence on the terminal load.

IV. Capacitance Voltage Between Lines and Ground

The capacitive voltage between lines and ground can be calculated as $C_o = q/V_c$, where q - electric charge in each of the lines. For a balanced three phase system, $q_a = -(q_b + q_c)$ and $q = C_oV_c = I\Delta t$ [3, 4], where I = current per line. I = $P/2V\cos\varphi = 450*10^6/2*330*10^3*0.92$ = 741.1A. The Δt is any time interval within the limit of the calculation. If we take Δt = 1 microsecond, and q = $741.1*10^{-6}$ Coulomb then, capacitive voltage will be defined as $V_c = q/C_o$ = $741.1*10^{-6}/3.125*10^{-6}$ = 237.15 Volts, where D=Distance between lines; C_o =Capacitance between lines; R_{eq} =Equivalent radius of double circuit conductor; C =Capacitance between conductors and the ground; q=Electric field of lines; X =Unit length of distance between two lines.

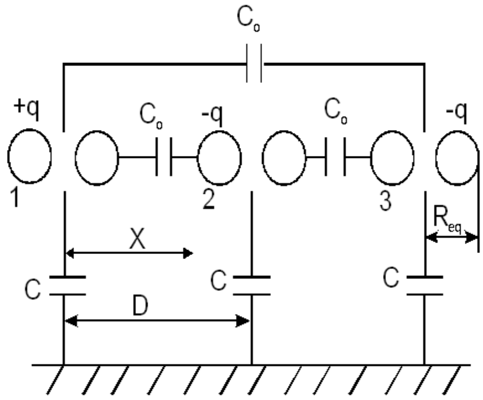

Fig.2. Three phase double circuit power line

From Fig.2, it is observed that 237.15Volts is the potential difference between any two lines. The voltage between the lines and the ground is: $V_o = q/C = Ic\Delta t/C$ = 0.316*10-3*10-6/3.05*10-12 = 103.6Volts. For a 330KV tower of conductor height, d_1 = 24.7m [5], voltage reaching the ground will be Vg = 103.6/(24.7-sag) = 4.20 Volts/m (for an assumed zero sag). This is far above the recommended contact voltage of (2 volts a.c.) for humans during normal operation of 50 Hz transmission lines. This voltage can come into contact with objects nearby especially electric towers and thunder protectors. However, the potential difference on tower can be minimized by effectively grounding them and by using high grade Insulators. The magnitude of this capacitive voltage on the towers and the effect it has on humans in contact with them will depend on two factors – effectiveness of grounding and contact resistance of humans.

Similarly, the strength of electric field, E which depends on the chosen location of x (see Fig. 2.0) in relation to $+q_1$ and $-q_2$ is found as the sum of the electric field of each of the two lines.

$E_1 = +q_1/2\pi xl\varepsilon_a$ and $E_2 = +q_2/2\pi(D-x)l\varepsilon_a$.

Summing the two equations, gives:

$E = E_1 + E_2 = q/(2\pi xL\varepsilon_a)(1/x + 1/D-x)$

$=[741.1*10^{-6}/(2*\pi*1*600*10^3*8.854*10^{-12})]**$

$(1+(1/6.75-1))$ = 26.076V/m, for x = 1,

where $\varepsilon_a = \varepsilon_r*\varepsilon_o$ – permeability of air and vacuum respectively, L - length of transmission lines.

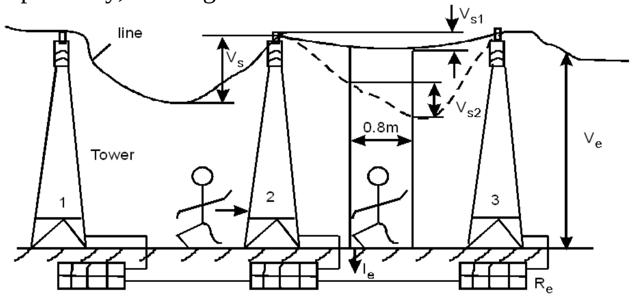

Fig.3. Schematic diagram of a healthy single circuit power line

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V. Potential Difference From Healthy Lines

A healthy line may pose the problem of shock at normal regime evident from the calculation above. Fig. 3.0 shows a pictorial representation of functional 330KV single circuit power line on metallic towers. The towers are effectively grounded with the resistance R_e.

A person standing between the second and the third tower with tensely pulled conductors may experience a shock

Table I. summarized electric field effect on distance between two transmission lines

Distance X, m	1	2	3	4	5	6
Electric field E, V/m	26.08	15.78	13.33	13.63	17.13	33.32

VI. Contact Voltage And Step Voltage

The contact voltage (V_{cont}) is made up of two components: (i) voltage emanating from leakage current and human resistance (I_LR_p) and voltage emanating from leakage current and top soil (I_LR_e). Therefore: $V_{cont} \leq I_LR_p + V_s$ while the step voltage is calculated as: $V_s = I_LR_e = I_L*1.5*\rho$, where $I_L = V/\cos\varphi*R_i = 330*10^3/0.92*5*10^6 = 0.07174$ A, R_p = human resistance, R_e = earth resistance, voltage known as step voltage (V_{s1}). Step voltage is the potential difference between two points on the ground at a distance of 0.80m [2]. For a sagged line, more than acceptable standard (dotted line) fig. 3.0, the step voltage (V_{s2}) tends to increase sharply. Two factors will determine the potential difference between the steps of an individual walking under the high tension line. 1) His position in relation to the pole. A maximum potential difference will be experienced at the middle of the two poles. 2) The sag of the power line. If the sagging increases, the step voltage may increase sharply. A person moving towards the second pole is likely to come under a contact voltage V_{cont}. Contact voltage is a measure of shift of the power line from normal vertical position with respect to the ground. The step voltage can be greatly increased during short circuit especially line-to-ground short circuit or loss of line. When there is line-to-ground short circuit, the step voltage can reach infinity. This is very dangerous for both man and beast within the range of the lost line. Its effect will depend on the resistance R_e of the top soil and the internal resistance of the individual person. At reasonably low voltage level, the step voltage can be reduced by reducing the steps of the individual around the short circuit zone as a protective measure, thereby minimizing the potential difference between steps.

R_i = resistance of ganged isolators for one line of 330KV, I_L = leakage current from electric towers, ρ = resistivity of top soil.

$V_{cont} \leq (0.07174*600 + 0.07174*1.5*200) = 64.566$ Volts.

For a person who has fallen a victim at the second tower, the actual voltage entering his body is: $V_p = V_{cont} - V_s = 64.566 - 21.522 = 43.044$ Volts.

VII. Corona Effect

Here, the effect of corona on a 330KV power line is investigated. Corona is in the form of electromagnetic discharge around transmission lines. It is characterized by a glowing ring, hissing sound and the characteristic smell of ozone. The process of ionization of the atmospheric air mass around the conductor caused by corona may lead to additional loss of energy, generation of electromagnetic wave and formation of ozone which adversely affects the surface of conductor joints. To reduce corona, the sizes of chosen conductor has to be optimum. Discharge in the form of corona takes place with the initial critical value of electric field strength (E_o), KV/cm [2].

$E_o = 30.3m_1[1+ (0.299/\sqrt{R_o})] = 30.30*0.82*[1+ (0.299/\sqrt{1.128})] = 31.84$ KV/cm, where $m_1 = 0.82$, (coefficient of roughness or smoothness of stranded conductors), R_o – radius of conductor (cm). For the 330KV, the maximum strength of electric field around the double circuit line is:

$E=K*0.354*V/[n*R_o*\log(GMD/GMR)]= 1.0752*0.354*330/2*1.128*\log(8.505/31.97*10^{-3}) = 21.06$ KV/cm

$K = 1 + n*(R_o/a) = 1 + 2*(1.128/30) = 1.0752$.

where K = a coefficient taking into account the number of conductors in a line, n = number of conductors in a circuit or line.

For corona to take place on the power line, the condition $1.07E \leq 0.9E_o$ has to be fulfilled, where E = normal electric field strength and E_o = critical value of electric field strength. There will be no corona if the maximum electric field intensity on the surface of any conductor does not reach $0.9E_o$. For horizontal conductors, electric field intensity on the middle of the conductor is about 7% higher than the values shown in the above calculation.

VIII. Heat Generated From Power Line

To calculate the heat generated from 330KV power line, we must view the double circuit line as a lossless one. Then, the active resistance R_o is neglected and the coefficient of oscillation δ is also neglected. In the absence of δ, the coefficient of distribution of electromagnetic wave becomes $\gamma = 0+j\beta$, where $j\beta$ = phase coefficient [3].

$j\beta = j\omega\sqrt{L_oC_o} = j*2*\pi*50\sqrt{1.12*10^{-6}*3.125*10^{-6}} = j5.88*10^{-4}$

The wave impedance $\underline{Z}_c = \sqrt{(L_o/C_o)}*Z_c = \sqrt{(1.12*10^{-6}/3.125*10^{-6})}* 605.981 = 362.78$ Kohm

$Z_c = \sqrt{(L/C)} = \sqrt{(1.12*10^{-6}/3.05*10^{-12})} = 605.981$ Kohm

The equation for the voltage on the power line at $\theta = 0$ is:

$V = V_1\cos\beta x + jI_1\underline{Z}_c\sin\beta x =330*\cos(5.88*10^{-4}*600)+j0.741.1*362.78*\sin(5.88*10^{-4}*600) = 329.994 + 1.6555 = 329.998$ KV

Voltage loss on the power line is $\Delta V = V_1 - V = 330 - 329.998 = 0.002$KV.

The equation for the current on the power line is:

$I = I_1\cos\beta x - j(V_1/\underline{Z}_c)\sin\beta x = 0.741.1\cos(5.88*10^{-4}*600) - (330/362.78) *\sin(5.88*10^{-4}*600) = 0.741086- j0.0056$

$\Delta I = I_1 - I = 0.7411 - 0.741086 - j0.0056 = 0.000014 - j0.0056 = 0.0056e^{89.86^\circ}$ KA

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The active power loss on the transmission line containing six lines is:

$P = IV = 6(0.000014 * 10^3 *0.002*10^3) = 0.1680$ watts.

This is equivalent to: 0.168*3600 = 604.8 joules/hour, where 1watt=1joule/sec.

IV. CONCLUSION

The result of the analysis of a healthy 330KV transmission line shows that the normal capacitive current I_c is 0.316mA as compared to the allowable value of 0.30mA which is about 5.55% above normal value. The capacitor voltage (shock voltage) is 4.2 Volts at a conductor height of 24.7 meters, 2Volts is the normal contact voltage at 50 Hertz. For corona to develop in the analyzed transmission line, the critical value of electric field intensity should be 31.84KV/cm as compared to the rated value of 30.0KV/cm for single circuit lines, for this calculation, the corona voltage is 21.06KV/cm which shows that corona will hardly develop in this double circuit line under consideration. The tower to body contact voltage was calculated as 43.04 Volts at a human resistance of 600 ohms and top soil resistance of 200 ohms. This voltage is fairly risky for human contact but can be reduced by increasing further the top soil resistance and reducing human resistance as can be seen from the calculation on section 6.0.

REFERENCES

[1] Baumshtein I. A. and Bazhanov C .A. Guide on High Voltage Electrical Installation Moscow Energoatomizdat pp. 449, 1989.
[2] Rozhkov L. D. and Kozulin V. S. Electrical Equipment of Power Stations and substations. M. Energoatomizdat pp. 236-238, 589-591, 1987.
[3] Evdokimov F. E. Principles of Theoretical Electrotechnics. Moscow Vishaya Shkola pp. 23 and 469, 1994.
[4] Kabardin O.F. Material Guide on Physics. Prosvishenye Moscow pp. 153, 1988.
[5] Orlov I. N. Editor-in-Chief. Data book on Electrotechnics. Energoatomizdat Moscow, Pp 302, 303 and 377, 1988.
[6] Dolin P. A. Data book on Safety Rules. Moscow Energoatomizdat pp.16, 1984.
[7] Zia A. Yamayee and Juan L. Bala Jnr. Electromechanical Energy Devices and Power Systems. John Wiley and sons Inc., 1994.
[8] Tokarev B. F. Electrical Machines. Moscow Energoatomizdat, 1990. pp. 132.

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