Prediction of Egyptian 500 kV Overhead Transmission lines Radio-Interference by Using the Excitation Function

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Abstract: - This paper presents applications of the excitation function on the prediction of the Radio-Interference (RI) of overhead transmission line, due to corona effect. These applications are done under different weather conditions such as: heavy rain, wet conductor and fair weather.
Also, this paper investigates the factors influencing the RI level namely; the height of conductors, phase spacing, number of subconductors in the bundle, diameter of subconductor and subconductor spacing in the bundle.
In this paper, it is shown that the RI level is dependent on the weather conditions. Where, the RI level under heavy rain has the maximum level, hence, it should be considered as a basic level of any overhead transmission line (OHTL).

Key-Words: - Corona, Excitation function, Radio interference, Overhead transmission line

1 Introduction

Radio interference (RI), as one of the corona effects, is an important factor in electromagnetic compatibility. The radio interference caused by corona discharge of high voltage transmission lines usually has a frequency between ten kHz and several MHz, hence it has a significant influence to the MW band of AM broadcasting and power line carrier communication system[1-2].

RI level of OHTL depends on many parameters. Some of these parameters are related to geometrical characteristics of the OHTL, such as its dimensions, its position in the space and the electric gradient on the surfaces of its conductors [3-4]. Other parameters depend essentially on environment, such as the surface state of the conductors and climatic conditions. The influence of the second group of these parameters with respect to the first group is far harder to estimate, i.e. the state of the surface of the conductors is practically difficult to measure [4].

Due to the need for overhead transmission line of higher voltage, a lot of researchers on radio interference and other corona effects have been conducted [3-5], based on them, several methods for predicting radio interference level are developed [3,5-6].

CISPR recommends two basic predicting methods of the RI level. One of them is an empirical method based on masses of experimental data, while the other method is an analytical method based on excitation function [7].

Actually, the excitation function method can not be totally viewed as an analytical method since the excitation function is obtained from corona cage tests.

Even so, the excitation function depends only on the characteristics of the space charge, without any relation to the geometry of the line [3]. On the other hand, the propagation procedure is also taken into account in the excitation function method. Therefore, the excitation function method shows more advantages than the empirical method [7]. Thus the excitation function method presents significance in theoretically and practically.

The calculation of radio interference by using excitation function method is divided into three stages.

The first stage is to calculate the excitation function and the interference current.

The second stage is to consider the propagation procedure to calculate the total interference currents

when corona occurring on the whole conductor. In this step, the phase-modal transformation is applied to solve the complex propagation procedure expressed by differential equations, which are obtained from the calculated result of the impedance matrix and capacitance matrix.
The third and final stage is to calculate the noise field at the required field points.

2 The Excitation Function Method

In multi-wire systems the corona streamer will induce current not only in the conductor that produces it but also in all other conductors. These currents depend on the characteristics of the conductor under corona and on the self and mutual capacitance of the conductors.

The basic steps in calculating the RI level due to corona on a three-phase 500 kV overhead transmission line are as follows:

Step1): Calculation of the excitation function, where its formula is fitted from a large amount of statistic data [3-4].

a) Heavy Rain

$$\Gamma_{hr} = \Gamma_r + 38log\left(\frac{2r}{3.8}\right) + k_n \quad (1)$$

Where;

n represents the number of sub-conductors in bundle,

r represents the sub-conductor radius cm,

Γ_r represents the heavy rain generation referred to a conductor diameter of 3.8 cm, which is independent on (n) for up to eight sub-conductors, and is obtained from the following relation [8]:

$$\Gamma_r = 78 - \frac{580}{E} \quad (2)$$

Where;
k_n represents an adjustment factor, which is dependent on (n) and conductor surface voltage gradient, and is obtained from the following relation [8]:

$$k_n = \begin{cases} 0\ dB\ for\ n \leq 8 \\ 5\ dB\ for\ n > 8 \end{cases} \quad (3)$$

Where;

E represents the conductor voltage gradient.

Wet-conductor [8]

$$\Gamma_{wc} = \Gamma_{hr} + C_w \quad (4)$$

Where;
C_w is an adjustment factor

$$C_w = 8.2 - 14.2/E_r \quad (5)$$

Where;

$$E_r = \frac{the\ operating\ conductor\ surface\ voltage\ gradient, E}{the\ 6 - dB\ gradient, E_c}$$

$$E_c = \begin{cases} 24.4/d^{0.24} & for\ n \leq 4 \\ \dfrac{24.4}{d^{0.24}} - 0.5(n-4) & for\ n > 8 \end{cases}$$

Fair-weather [9]

$$\Gamma_{fair} = \Gamma_{wc} - 17\ dB \quad (6)$$

Step 2): Calculation of the generated current densities at z =0, which are given in terms of the individual generation function by [8-9]:

$$[i] = \frac{[C]}{2\pi\varepsilon_o}[\Gamma] \quad (7)$$

Where;
ε_o represents the free-space permittivity,
$[C]$ represents the matrix of capacitances, which equals to the inverse of the Maxwell potential coefficient matrix $[P]$. Where, the elements of $[P]$ are given, with the help of Fig. (1), by the following relations [10]:

$$P_{ii} = ln\frac{2H_i}{r_i}$$

$$P_{ij} = ln\frac{D_{ij}}{d_{ij}}$$

$$D_{ij} = \sqrt{\left(x_i - x_j\right)^2 + (y_i + y_j)^2}$$

$$d_{ij} = \sqrt{\left(x_i - x_j\right)^2 + (y_i - y_j)^2}$$

Step 3): Calculation of the initial phase voltage $[v_0]$ from these initial phase currents, as follows [9-12]:

$$[v_0] = [Z_0][i_0] \quad (8)$$

Where; $[Z_0]$ is the surge impedance matrix, which can be obtained by the lossless impedance matrix as follow:

$$[Z_0] = \frac{1}{2ð}\sqrt{\frac{ì_o}{å_o}}[P]$$

$$[Z_0] = 60[P]$$

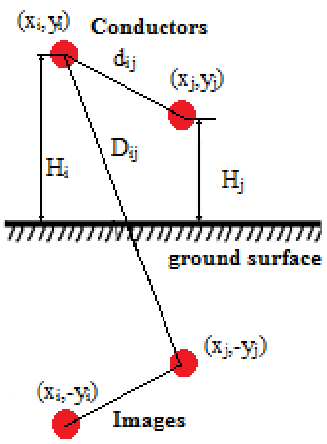

Fig. 1 Configuration for the calculation of the Maxwell's coefficients

Step 4): Transformation of these initial phase voltages to initial modal voltages by:

$$\left[v_o^{(m)}\right] = [s]^{-1}[v_0]$$

$$[v_o^m] = 60[s]^{-1}[\tilde{A}] \quad (9)$$

Where, $[s]^{-1}$ is the inverse of the modal transformation matrix $[s]$. Calculation of the elements of the transformation matrix $[s]$ requires solving the matrix $[D]$ for the eigenvectors, where the matrix $[D]$ is given by:

$[D] = [Y][Z]$

Where $[Z]$ and $[Y]$ are the series impedance and the shunt admittance of the conductor, respectively, and they can be calculated as follows:

$[Z] = [R] + jw[L]$

$[Y] = [G] + jw[C]$

In which the inductance matrix $[L]$ is given by:

$$[L] = \frac{ì_o}{2ð}[P]$$

and the capacitance matrix $[C]$ is given by:

$$[C] = 2ðå_o[P]^{-1}$$

The elements of the resistance matrix $[R]$ are frequency dependent and equal the sum of the high-frequency resistance of the conductors and earth correction terms that take into account the lossy nature of the earth.

For practical cases, the conductance matrix $[G]$ is so small that it may be neglected.

Step 5): One half of these modal voltages $\left[v_o^{(m)}\right]$ will travel in either direction away from the point of generation.

At a distance, z, each modal component will have been attenuated to yield:

$$\left[v(z)^{(m)}\right] = \frac{1}{2}\left[e^{-\alpha^{(m)}z}\right]\left[v_o^{(m)}\right] \quad (10)$$

$$\left[v(y)^{(m)}\right] = 30\left[e^{-\alpha^{(m)}z}\right][S]^{-1}[\tilde{A}]$$

Where $\left[e^{-\alpha^{(m)}z}\right]$ is a diagonal matrix of attenuation factors and $\alpha^{(m)}$ is the real part of the complex propagation constant.

$\lambda^{(m)} = \alpha^{(m)} + j\beta^{(m)}$

Step 6): Transformation of these voltages back to phase voltages by using the following relation:

$$[v_o] = [S]\left[v_o^{(m)}\right] \quad (11)$$

Step 7): Calculation of the field strength at required lateral distance from the line due to these voltages [3]:

$$e_i(x_a, y_a) = [F_1 \ F_2 \ F_3][P]^{-1}\begin{bmatrix} v_{1iz} \\ v_{2iz} \\ v_{3iz} \end{bmatrix} \quad (12)$$

Where; $[F_1 \ F_2 \ F_3]$ is the field factor matrix, its elements are defined, according to Fig. 2, as follows:

$$F_i(x) = \frac{y_i - y_a}{(y_i - y_a)^2 + (x_i - x_a)^2} + \frac{y_i + y_a + 2\delta}{(y_i + y_a + 2\delta)^2 + (x_i - x_a)^2}$$

$$\delta = \sqrt{\frac{\rho}{\pi\mu F}}$$

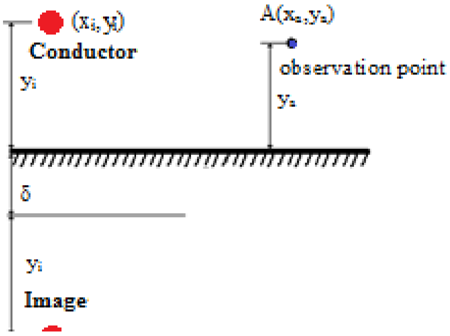

Fig. 2 Configuration for the calculation of the field factor matrix

Step 8): Integration over entire line length to determine the total field strength $E_i(x_a, y_a)$ due to a uniform distribution of corona on conductor i, by:

$$E_i(x_a, y_a) = \sqrt{2\int_0^{\infty} e_i(x_a, y_a)dz} \qquad (13)$$

The integration in equation (13) can be done analytically by:

$$E_i(x_a, y_a) = \left[2\sum_{a=1}^{3}\sum_{b=1}^{3}\left\{\frac{W_i^{(a)}W_i^{(b)}}{\alpha^{(a)}+\alpha^{(b)}}\right\}\right]^{1/2} \quad (14)$$

Where;

$W_i^{(m)} = 30[F]_{1\times3}[P]_{3\times3}^{-1}[G]_{3\times1}$

and the elements of matrix $[G]$ are given by:

$G_j = S_{jm}T_{mi}\Gamma_i$

Where; S_{jm} is the (j,m) element of $[S]$, the modal transformation matrix; and T_{mi} is the *(m,i)* element of $[S]^{-1}$.

Step 9): Calculation of the total RI field strength $E(x_a, y_a)$ by sum up the contributions from each phase, according to the following rules [8-12]:

Assume: $E_1 \geq E_2 \geq E_3$

If $E_1 \geq E_2 + 3$, then $E = E_1$

Otherwise $E = \frac{E_1+E_2}{2} + 1.5$

The structural parameters of the Egyptian 500 kV transmission line, which presented in Fig. 3, are listed in Table (1). The soil resistivity takes the value of 100 Ω.m, and the resistivity of the conductors takes the value of 2.4 Ω/mm2/km.

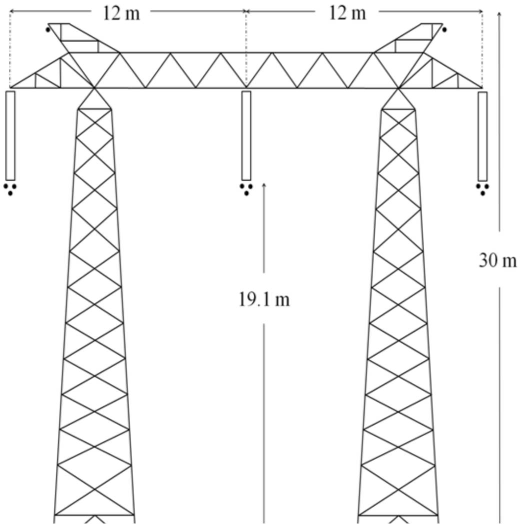

Fig.3 Power line tower dimensions of 500 kV

Table 1 Data of 500 kV Single-Circuit Overhead Transmission Line

Tower span *L*	400 m
Maximum conductor height *H*	19.1 m
Spacing between adjacent two phases *S*	12 m
Number of subconductor per phase *N*	3
Diameter of a subconductor $2r_c$	30.6 mm
Spacing between subconductors *B*	47 cm
Minimum clearance to ground *h*	9 m
Number of the ground wires N_g	2
Diameter of the ground wire r_g	11.2 mm

3 Results and Discussion

The field points at which the values of the RI level are required to be calculated, in the following results, are located at one meter above the ground surface and a distance away from the center phase.

Fig. 4 shows the effect of using excitation functions of various weather conditions namely; heavy rain, wet conductor, and fair weather on the calculated values of the RI level in dB above 1 μV/m^2. It is seen that the heavy rain weather condition has a greater values of RI level that can be explained as: under atmospheric pollution conditions such as heavy rain, the number of streamers increases along the length of the conductor, hence that increases the RI level. As the RI level under heavy rain has the maximum level, it will be considered as a basic level and will be considered in the following results.

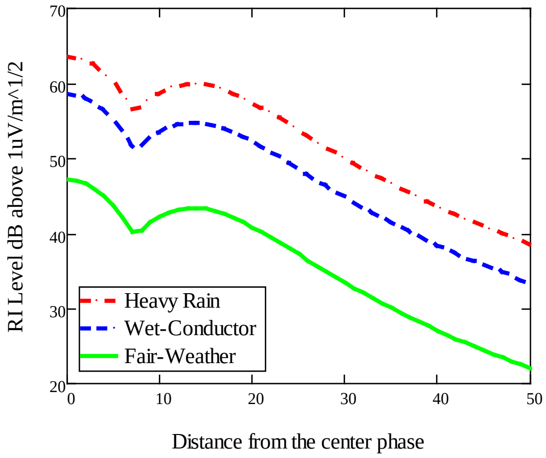

Fig. 4 Effect of different weather conditions on the RI level

Fig. 5 shows the effect of the height of OHTL conductors on the calculated values of the RI level under heavy rain weather condition. It is noticed that with the increasing of the conductors' height the RI level decreases that because the source of the RI level becomes more far from the field points, at which the RI level are required to be calculated.

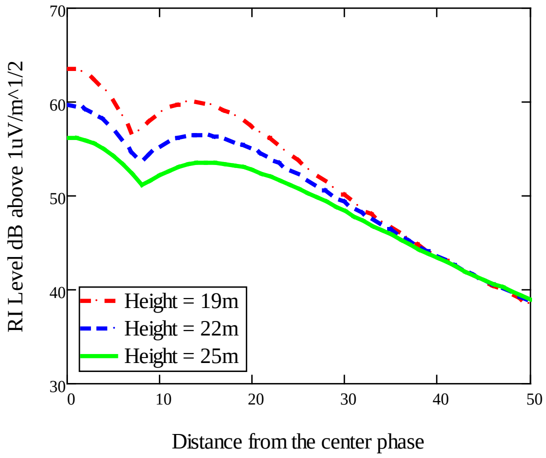

Fig. 5 Effect of the height of the OHTL conductors on the RI level

Fig. 6 shows the effect of the phase spacing of OHTL conductors on the calculated values of the RI level under heavy rain weather condition. It is noticed that with the increasing of the phase spacing the RI level decreases under the three phases and increases at a distance far from the three phases that can be explained as follow: as the spacing between the phases is increased the conductors voltage gradient decreases, hence the RI level under the three phases is decreased; while at a distance relatively far from the three phases, the effect of the other two phases in the cancelation of the RI level produced by the outer phase is decreased as the spacing between the phases is increased, hence under these distances the RI level is increased.

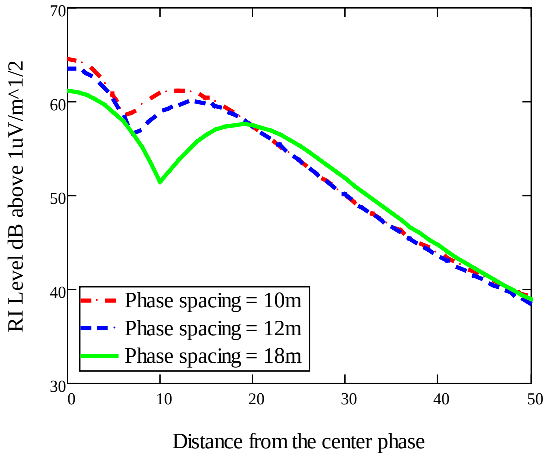

Fig. 6 Effect of the phase spacing on the RI level

Fig. 7 shows the effect of the number of the subconductors in the bundle on the calculated values of the RI level under heavy rain weather condition. It is noticed that with the increasing of the number of the subconductors the RI level decreases. That can be explained as follow: increasing the number of the subconductors will be resulted in decreasing in the conductors voltage gradient, hence the RI level will be decreased.

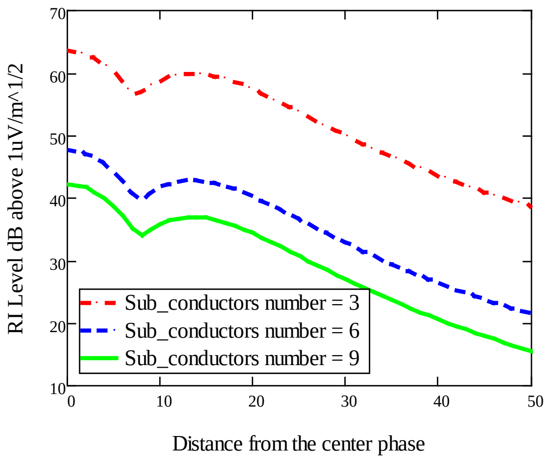

Fig. 7 Effect of the subconductor number on the RI level

Fig. 8 shows the effect of the radius of the subconductors in the bundle on the calculated values of the RI level under heavy rain weather condition. It is noticed that with the increasing of the radius of the subconductors the RI level is slightly decreased. That can be explained as follow: as the radius of the subconductors is increased the conductors voltage gradient decreases, hence the RI level is decreased, but in the same time by the definition of the excitation function it is noticed that the values of the excitation function are increased as the radius of the subconductors is increased that results in an increasing in the RI level; hence the final effect of the increasing of the radius of the subconductors results in a slightly decreasing in the values of the RI level.

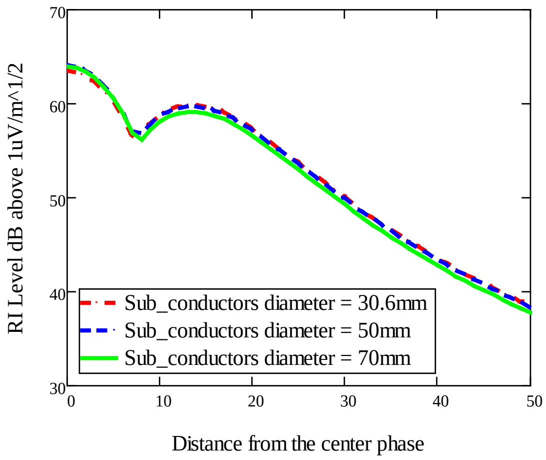

Fig. 8 Effect of the radius of the sunconductors on the RI level

Fig. 9 shows the effect of the spacing between the subconductors in the bundle on the calculated values of the RI level under heavy rain weather condition. It is noticed that with the increasing of the spacing between the subconductors the RI level is decreased.

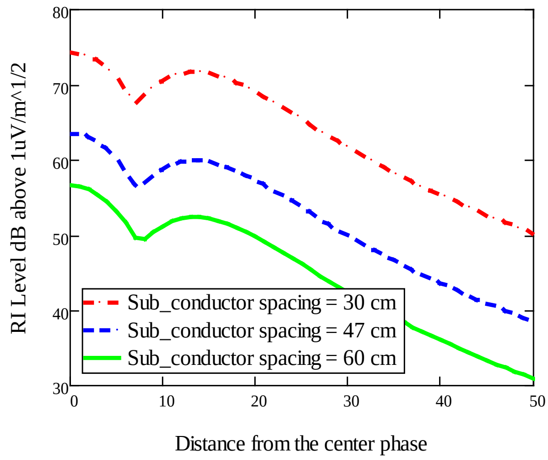

Fig. 9 Effect of the spacing between the subcondutors on the RI level

That can be explained as follow: with the same number of the subconductors, as the spacing between them increases the conductor voltage gradient decreases, hence the RI level will be decreased. Table 2 summarizes the previous results.

Table 2 Summarization of the obtained results

Distance from the center phase	Weather Conditions H=19.1 m, S=12 m, N=3, $2r_c$ =30.6 mm, B=47 cm			Conductor Height H (m)		Spacing between phases S (m)		Subconductor number N		Subconductor diameter $2r_c$ (mm)		Spacing between sunconductor B (cm)	
	Fair Weather	Wet Conductor	Heavy Rain	22m	25m	10 m	18 m	6	9	50 mm	70 mm	30 cm	60 cm
0 m	47.139	58.557	**63.593**	59.669	56.241	64.572	61.175	47.675	42.199	64.072	63.966	74.334	56.647
10 m	42.308	53.673	**58.833**	55.231	52.261	60.916	51.417	41.662	35.809	58.646	58.024	70.539	51.225
20 m	40.848	52.214	**57.374**	54.974	52.746	57.399	57.504	40.228	34.38	57.2	56.588	69.058	49.78
30 m	33.471	44.837	**49.997**	49.236	48.349	50.004	51.787	32.845	26.996	49.82	49.205	61.685	42.399
40 m	27.062	38.428	**43.588**	43.535	43.372	43.867	44.655	26.429	20.578	43.407	42.789	55.284	35.986
50 m	22.063	33.429	**38.589**	38.818	38.991	39.093	38.926	21.422	15.569	38.404	37.783	50.292	30.983

4 Conclusion

The RI level is dependent on the weather conditions. Where, the RI level under heavy rain has the maximum level, hence, it should be considered as a basic level of any overhead transmission line (OHTL).

Increasing both of the OHTL heights, the phase spacing of OHTL conductors, the number of the subconductors in the bundle and the spacing between the subconductors in the bundle reduce the calculated values of the RI level.

Increasing the radius of the subconductors has a slight effect on the calculated values of the RI level.

Between these parameters, it is noticed that increasing the number of sub-conductors in the bundle and increasing the spacing between the subconductors in the bundle are the most effective ways to reduce the RI level.

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