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# Impact of Corona Discharge and Radio Noise Using Monte Carlo Analysis in EHV Transmission Line

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***Abstract: -*** The paper investigates the impact of Corona discharge on Extra High Voltage (EHV) transmission lines and elucidates the importance of Corona Radio Interference (RI) and Television Interference (TVI). A statistical model based on Monte Carlo simulation is evaluated to estimate the influence of variable parameters such as atmospheric conditions, supply frequency, supply voltage on the corona quantities. To find out the probability distribution of the parameters and compute the probability of corona effect lying within certain limits, when parameters changes randomly within specified range. By employing this analytical approach, the research provides valuable insights into the complex interplay between Corona effect and transmission line performance, offering practical implications for the design and maintenance of EHV systems. Overall, the paper contributes to a deeper understanding of Corona's influence on EHV transmission lines and provides actionable recommendations for optimising their reliability under changing conditions.

***Keywords:*** Corona, Monte Carlo Analysis, Radio noise, EHV Transmission.

## I. INTRODUCTION

Extra High Voltage (EHV) transmission lines play a pivotal role in the global electricity network, enabling the long-distance transmission of power from generation plants to distribution centres[1].These networks form the backbone of modern power systems, enabling the delivery of large amounts of energy from generation sources to distribution points. However, the operation of these lines is often accompanied by corona discharge [2].Corona discharge occurs when the electric field strength exceeds a critical value, ionizing the surrounding air. The ionization of air results in to formation of a faint glow and hissing or crackling audible noise [3].While corona discharge is a natural consequence of high electric fields, it has significant negative implications for EHV transmission systems [4].EHV transmission lines, where voltages typically range from hundreds of kilovolts to even several megavolts, the conductor itself is the major source corona discharge. This corona discharge creates Audio Noise (AN), radio interference (RI), television interference (TVI) and corona loss (energy loss) [5]. Therefore, understanding the effects of corona discharges in EHV transmission lines is crucial for ensuring the efficiency, reliability, and safety of power delivery infrastructure. In addition, knowing the exact level of the Audio Noise (AN), radio interference (RI), television interference (TVI) and corona loss (energy loss) is very significant for designing a transmission line. However, the calculation of the corona noise level at the line terminations is very complex and requires considerable effort.

The previous studies have derived empirical formulas and analytical solutions to evaluate the corona performance of transmission line designs. However, these empirical formulas cannot accurately evaluate the corona performance. At the same time analytical solutions are difficult to obtain due the complex interconnection of various factors. Which raises the need for a valuable tool for evaluating corona discharge. The Monte Carlo simulation can be an important tool for evaluating corona discharge in electricity. The monte Carlo simulations can be used to simulate a range of input parameters. The simulation results can be used to determine the sensitivity of corona discharge (output) parameters to changes of input parameter. Further the interrelations between input parameters and corona discharge can be used to assess the impact on system performance.

The paper delves into the intricate effects of corona discharges in Extra High Voltage (EHV) transmission lines, highlighting the dynamic interplay among numerous parameters, operational variables, and atmospheric conditions. It underscores the challenge of maintaining constancy across these factors over time, with their cumulative contributions shaping corona effects in a multifaceted manner. Particularly, determining the disruptive critical voltage $V_0$, necessitates assigning average values for factors like conductor irregularity $m_0$, subject to fluctuations induced by weathering effects on the conductor.

While certain parameters remain reliably constant, others are susceptible to errors of evaluation and temporal variations, underscoring the need for comprehensive assessment frameworks. The paper presents the significance of evaluating corona quantities like disruptive critical voltage$V_0$, visual critical voltage Vv, corona loss Pc, and radio and television interference (RI and TVI), accounting for the nuanced variations across these parameters. This holistic approach offers invaluable insights into managing corona effects in high-voltage systems, essential for ensuring reliable and efficient transmission line operations amidst evolving environmental and operational conditions.

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In this study the effect of input parameters like - Irregularity factor, conductor diameter, lateral distance from antenna to nearest phase, barometric pressure and Frequency is analyzed on corona discharge parameters – corona loss, radio interference and TV interference.

## II. FORMATION OF CORONA AND ITS ANALYSIS

Corona on transmission lines uses power loss, radio and television interference and audible noise near the transmission line At EHV levels, the conductor itself the major source of RI,TVI So the ususal intrest consists in evaluating corona quantities viz, the discharge critical voltage, visual critical voltage and corona loss, radio interferncec and television interference due to corona The expressions used for the corona quantities are as follows:

$$V_0 = 21.1\delta m_0 r\, ln\frac{D}{r} kv \text{ ------------------------(1)}$$

$$V_v = 21.1\delta m_v r \left[1 + \frac{0.3}{\sqrt{\delta r}}\right] ln\frac{D}{r} kv \text{ -------------(2)}$$

Peterson's formula for corona loss is as follows, When the ratio (V/$V_0$ ) is less than1.8 , Peterson's relationship holds good. (6)

$$P_c = \frac{1.11066 \pm 10^{-4} f V^2 F}{\left[ln\left(\frac{2D}{d}\right)\right]} \text{ --------------------(3) Kw/Km/conductor}$$

Here F is the corona factor, is a function of the ratio of V to $V_0$.
Typically,
For fair weather corona, **Table 1** shows the empirical values of F.

| (V/$V_0$) | 0.600 | 0.800 | 1.00 | 1.20 | 1.4 | 1.6 | 1.8 | 2.0 | 2.2 |
|---|---|---|---|---|---|---|---|---|---|
| F | 0.012 | 0.018 | 0.05 | 0.08 | 0.3 | 1.0 | 3.5 | 6.0 | 8.0 |

**Table 1: Empirical Values of F.**

For wet weather corona, determine the factor F using V/0.8 $V_0$.

RI=50+K ($E_m$-16.95) +17.3686 ln ($d/3.93$)+$F_n$+13.8949 ln ($20/D_1$)+$F_{Fw}$ --------------(4)

$$TVI = RI - 20\, log_{10} - \left[\phi \left[\frac{1+\left(\frac{R}{h_1}\right)^2}{1+\left(\frac{15}{h_1}\right)^2}\right]^{\frac{1}{2}}\right] + 3.2 \text{ --------------- (5)}$$

$$\delta = 0.386\ p / 273+t \text{ ---------------------------- (6)}$$

## III. MONTE CARLO TECHNIQUE & ITS COMPARISION

Monte Carlo technique is a powerful computational technique used to model complex systems by generating random samples from probability distributions. In the context of EHV transmission lines, Monte Carlo simulation can be employed to analyze the stochastic nature of corona discharge and its impact on radio noise generation. The simulation involves the following steps:

1. Modelling the geometry and electrical parameters of the transmission line.
2. Defining probability distributions for input parameters such as voltage, conductor spacing, atmospheric conditions, and environmental factors.
3. Iteratively simulating corona discharge events based on random samples drawn from the input distributions.
4. Calculating the resulting radio noise spectra for each simulated scenario.

The Monte Carlo method, a statistical technique, is employed in this study to analyse the effects of corona on Extra High Voltage (EHV) lines. By simulating various parameters simultaneously, Monte Carlo simulation offers a comprehensive understanding of corona phenomena. This method allows for the modelling of patterns in data affected by randomness and uncertainty, enabling inferences about the studied process. Monte Carlo methods entail generating suitable random numbers via random number generators to solve computational problems effectively. Among its applications, numerical optimization stands out, as Monte Carlo optimization facilitates easy determination of maximum and minimum values of corona quantities compared to alternative optimisation techniques. In statistical methods, including Monte Carlo, system parameters are typically assumed to follow normal distributions, with mean values representing nominal values and standard deviations reflecting parameter variability. Consequently, the mean and standard deviation of input variables determine those of all dependent variables in the statistical analysis.

**Comparison of Monte Carlo Technique with other techniques:**
The consideration of parameter variation in engineering design processes is crucial for ensuring robustness and reliability. In this context, various methodologies such as worst-case analysis, sensitivity analysis, and Monte Carlo simulation offer distinct approaches with their own sets of advantages and challenges.

1. Worst-case analysis, while conceptually straightforward, often proves to be a cumbersome and labour-intensive method. Its application demands meticulous consideration of extreme scenarios, which can be time-consuming and prone to oversight
2. Sensitivity analysis, on the other hand, allows for the examination of individual parameter variations while holding others constant at their nominal values. This method facilitates a more focused exploration of the impact of specific parameters on the overall system performance. However, the restriction of tolerance variation to a fixed percentage for all parameters may limit its adaptability to complex systems with diverse sensitivity profiles.
3. In contrast, Monte Carlo simulation emerges as a powerful tool capable of handling multiple parameter variations simultaneously. By allowing for the exploration of interactions between different parameters, Monte Carlo simulation offers a comprehensive understanding of system behaviour under diverse conditions. Furthermore, its flexibility in accommodating different tolerance ranges for each parameter enhances its applicability to real-world engineering challenges.

In the context of transmission line design considering Corona effects, the insights provided by Monte Carlo simulation can be particularly valuable for design engineers. By revealing the nuanced interplay between various parameters, Monte Carlo analysis equips engineers with the information needed to optimize design decisions and ensure the reliability of transmission systems in the face of variable operating conditions.

## IV. METHODOLOGY:

For a 400 kV EHV line, The variation of random variable Xi is from its nominal value ui is ± αi.

- The upper limits of ui are U= (1+( αi/100)) ui
- The lower limits of ui are L= (1-( αi/100)) ui

If the random variables takes any value between its upper and lower limits then following expression gives, the 3Σi value of its normal distribution.

$$\mathbf{3\Sigma i = \frac{U-L}{2} = \frac{\alpha iui}{100}} \text{ ----------------(7)}$$

Normal distribution with a mean value ui and standard deviation Σi is applied to each of the random parameters, atmospheric conditions and operating variables on which the corona quantities depend. The mean value of these parameters/ variables/operating conditions is considered as respective intermediate values within the given range.

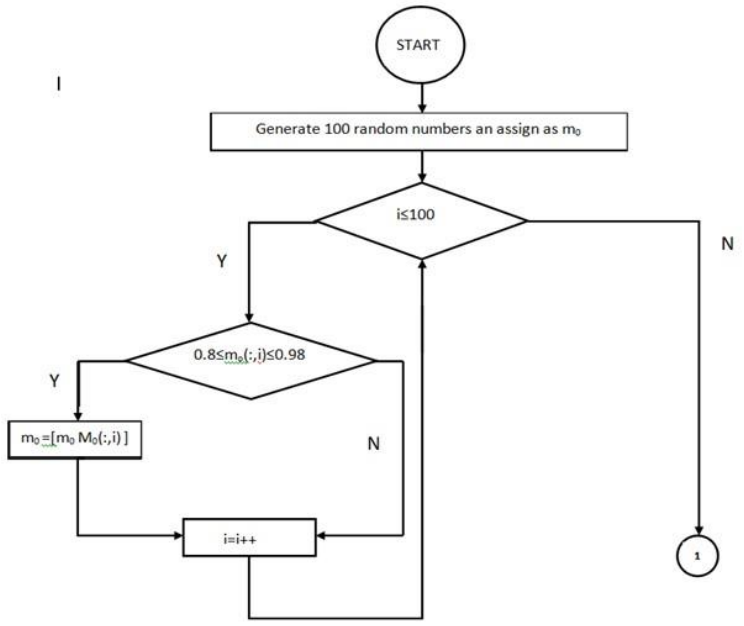
- By using equation no-7, standard deviation of each random variable can calculate. which is shown in table no- II
- By considering the random variation of parameters/atmospheric conditions / operating variables about their mean value, corona quantities given in expressions (1) to (5) can determined. For example, the barometric pressure is a function of altitude. At sea level value of pressure is 76cm Hg and at height about 6000m, value of pressure is 35 cm. similarly, temperature can also vary over wide range of 10 ° to 45 ° depending upon atmospheric condition. Here each random variable is assumed to vary by ± αi% around its nominal value and Monte Carlo simulation used.
- This table II gives ranges of different parameter, atmospheric conditions and operating variables for a 400 KV line.

**Table II : Mean & Std. Deviation Values of random Variables for 400kv lines**

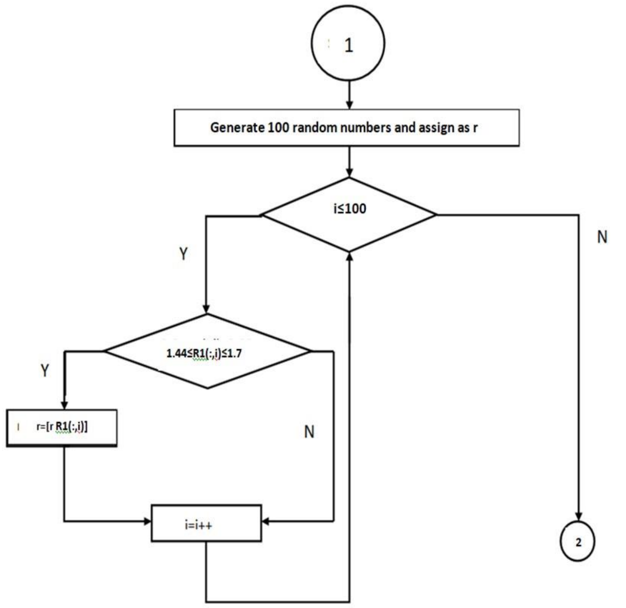
| | **Range of Random Variables Xi** | **Mean value ui** | **Tolerance of Random Variable** ± αi% | **Standard deviation 3Σi** |
|---|---|---|---|---|
| Irregularity factor ,$m_r$ | 0.7-0.98 | 0.84 | 16.670 | 0.046 |
| Pressure (p), Cm Hg | 35-76 | 55 | 36 | 6.600 |
| Irregularity factor, $m_0$ | 0.8-0.98 | 0.89 | 10.120 | 0.030 |
| Conductor Radius (r), cm | 1.44-1.76 | 1.6 | 10.00 | 0.053 |
| Spacing (D), cm | 405-495 | 450 | 10.00 | 15 |
| Temperature (t), 0C | 10-45 | 27 | 60.00 | 5.400 |
| Operating Voltage (v), Line kV | 380-420 | 400 | 5.00 | 6.66 |
| Supply Freq (f), Hz | 49.95-50.041 | 50 | 0.083 | 0.015 |
| Line Height(b),m | 18-22 | 20 | 10 | 0.660 |

| | | | | |
|---|---|---|---|---|
| Lateral distance from line (R), m | 13.5-16.5 | 15 | 10 | 0.500 |
| Max electrical field at Conductor surface (Em), kV/cm | 16.15-17.85 | 17 | 5.00 | 0.283 |
| Carrier freq (Φ), MHz | 74.93-91.58 | 83.25 | 10 | 2.78 |

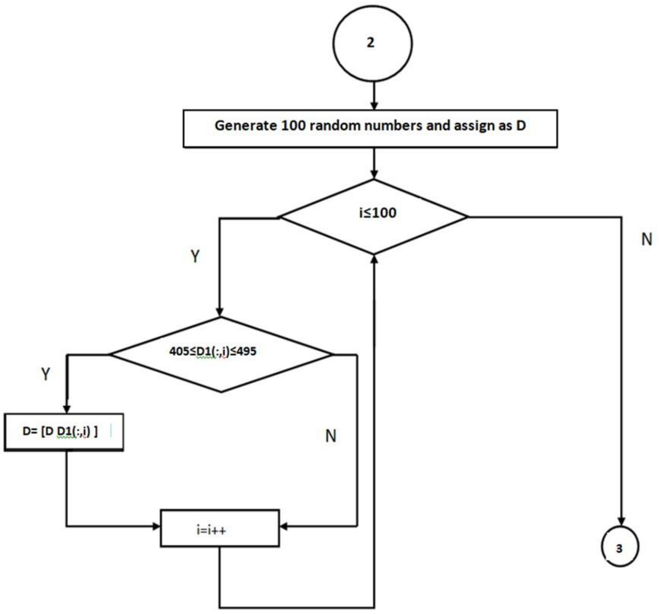
- Flow chart -1, flowchart -2 and flowchart -3 represents generation of random numbers of irregularity factor $m_0$, conductor radius r and spacing between two conductor's D respectively, within their specified range. they are used to find value of $V_O$- disruptive critical voltage by Monte Carlo simulation, which is representing by flow chart no 4.



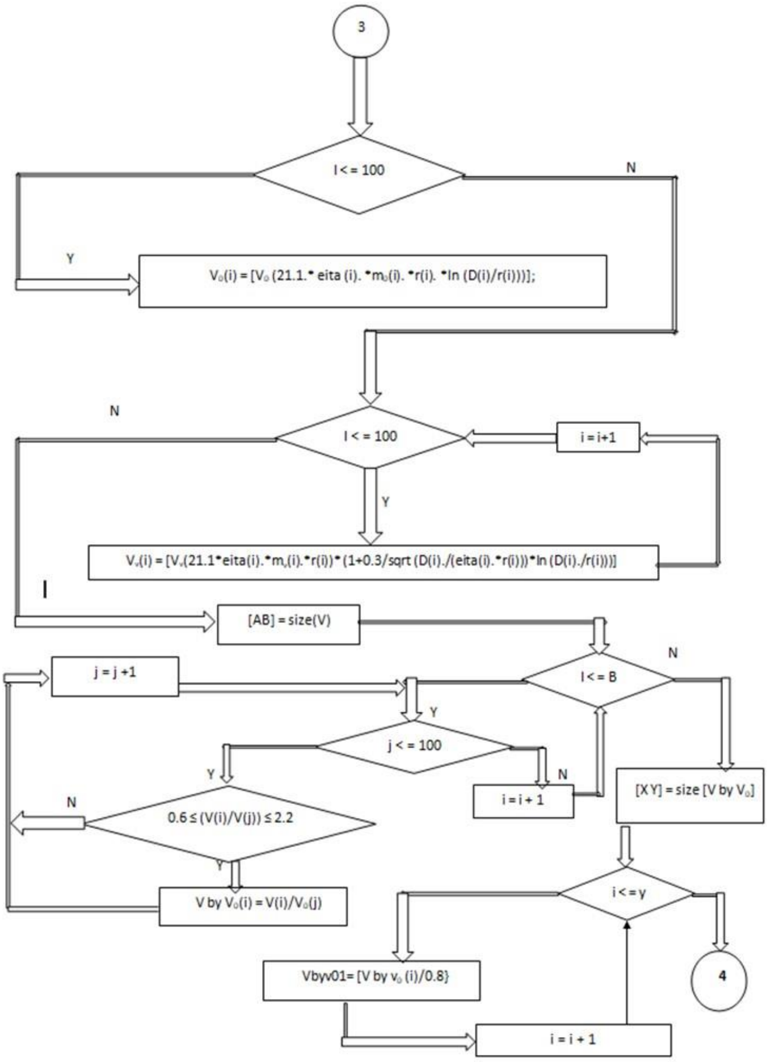
**Flow chart-1**



**Flow chart -2**



Flow chart -3



Flow chart -4

## V. RESULTS AND DISCUSSION

The results of two trials of a Monte Carlo simulation for corona effects input data and output data shown in Table III and Table IV respectively. Each row of Table III and table IV corresponding to a single trial show respectively the input parameter values and the output variables. The results of One hundred trials of Monte-Carlo simulations for corona effects input data and output ut data by using uniform random numbers for 400 kV line shown in Table V and Table VI respectively. Table VII however shows that the maximum value of RI can reach 63.39 dB when the parameter lies within the assumed ranges of Table II. In foul weather it can reach 76.37db at frequency 83.25MHz. Table VI and VII shows results of Monte Carlo simulations by using uniform and non-uniform random numbers respectively. For more accurate results the number of trials are increased to hundred. The output quantities are Vo, Vv, Pc, RI & TVI. It is worth nothing that the average values are fairly close to the nominal values.

**Table III Input Data - Two trials of Monte Carlo simulation for corona effect**

| Input Data | $m_r$ | p, cm Hg | $m_0$ | r, cm | D, cm | t, °C |
|---|---|---|---|---|---|---|
| Nominal | 0.84 | 55 | 0.89 | 1.5 | 550 | 27 |
| Trial 1 | 0.82 | 40 | 0.944 | 1.46 | 520 | 13.50 |
| Trial 2 | 0.78 | 48.96 | 0.940 | 1.44 | 557 | 41.45 |
| **Input Data** | **V, Line kV** | **$f$ Hz** | **h, m** | **R, m** | **$E_m$KV/cm** | **Φ, MHz** |
| nominal | 345.0 | 60 | 20 | 15 | 19 | 83.25 |
| Trial 1 | 335 | 59 | 18 | 13.60 | 18 | 76.72 |
| Trial 2 | 343.5 | 60.02 | 20.55 | 14.49 | 18.97 | 82.97 |

**Table IV Output Data- Two trials of Monte Carlo simulation for corona effect**

| Output Data | $V_O$, KV/phase | $V_v$, KV/phase | $P_{c,}$ KW/km (3-phase) | RI, DB Above 1 µ$V/m$ | TVI, DB Above 1 µ$V/m$ |
|---|---|---|---|---|---|
| Nominal | 172.44 | 214.16 | 1.43 | 60.30 | 25.15 |
| Trial 1 | 91.89 | 106.88 | 137.34 | 50.089 | 20.90 |
| Trial 2 | 102.97 | 112.81 | 77.84 | 60.19 | 25.12 |

**Table V - Monte Carlo simulation for corona effects - input data for 400kv line**

| Input data | $m_r$ | p,cm Hg | $m_0$ | r, cm | D, cm | t, °C |
|---|---|---|---|---|---|---|
| Nominal | .84 | 55 | .89 | 1.6 | 450 | 27 |
| **Input data** | **V, line KV** | **f, Hz** | **H, meter** | **r, meter** | **Em, KV/cm** | **Φ, MHz** |
| Nominal | 400 | 50 | 20 | 15 | 17 | 83.25 |

**Table VI - One hundred trials of Monte-Carlo simulations for corona effects-output data.**

| Output Data | Critical Disruptive Voltage $v_0$ kV/phase | Critical Visual Voltage $v_v$ kV/phase | Corona Loss $P_c$ Kw/km (3 phase) | Radio interference RI, db | TV interference TvI, db |
|---|---|---|---|---|---|
| Nominal | 137.37 | 184.55 | 4.73 | 55.33 | - |
| Max | 195.56 | 241.94 | 6.78 | 59.37 | 24.41 |
| Min | 86.13 | 138.44 | 2.53 | 50.14 | 14.96 |
| Average | 140.85 | 190.18 | 4.66 | 54.76 | 19.42 |
| Std. deviation | 48.94 | 50.81 | 2.29 | 2.29 | 4.39 |

**One hundred trials of Monte-Carlo simulations for corona effects - output data.**
**(By using non-uniform random numbers)**
**TABLE –VII**

| Output Data | Critical Disruptive Voltage $v_0$ kV/phase | Critical Visual Voltage $v_v$ kV/phase | Corona Loss $P_c$ Kw/km (3 phase) | Radio interference RI, db | TV interference TvI, db |
|---|---|---|---|---|---|
| Max | 197.22 | 243.57 | 6.47 | 60.17 | 25.11 |
| Min | 94.03 | 135.60 | 2.41 | 50.70 | 15.72 |
| Average | 145.62 | 189.58 | 4.44 | 63.39 | 28.70 |
| Std. deviation | 51.59 | 53.98 | 2.02 | 4.97 | 4.69 |

The Monte Carlo simulation offered insights into the statistical distribution of corona discharge intensities and the corresponding levels of radio noise across various operational scenarios. Through analysis of the simulation outcomes, we pinpointed the critical factors influencing corona discharge and radio noise generation in EHV transmission lines. Moreover, the simulation enabled us to evaluate the effectiveness of different mitigation techniques—such as corona rings, spacer dampers, and treatments for conductor surfaces—in reducing emissions of radio noise.

## VI. CONCLUSION AND FUTURE DIRECTIONS

In conclusion, Monte Carlo simulation offers a valuable tool for studying the relationship between corona discharge and radio noise in EHV transmission lines. By accurately modelling the stochastic nature of corona discharge events, researchers can gain a deeper understanding of the factors influencing radio noise generation and propagation. Future research directions may include the refinement of simulation models to incorporate additional factors such as wind effects, pollution accumulation, and dynamic line operating conditions, further enhancing the accuracy and applicability of the analysis.

The statistical model proposed herein not only offers a robust tool for analyzing corona performance but also holds broad applicability and flexibilities. These findings are particularly valuable to engineers tasked with designing transmission lines and conductor design, as they provide insights into the intricate dynamics of corona effects, thereby aiding in the creation of more efficient and reliable systems. Overall, this research contributes to advancing our understanding of corona phenomena in transmission lines and underscores the significance of employing advanced computational techniques in electrical engineering applications.

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**Notations**

D : spacing between two conductors in centimeters.

$D_1$ : radial distance from conductor to antenna. M=$\sqrt{h^2+R^2}$

d : conductor diameter, cm

$E_m$ : maximum electric field at conductor kV (rms)/cm

F : corona factor determine by test and is a function of ratio of V to $V_0$

$F_{Fw}$: 17 for foul weather, 0 for fair weather

$F_n$: -4 dB for single conductor = 4.3422 ln $(n/4)$ for n>1, n = number of conductors in bundle.

f : supply frequency in hertz.

h : height, m

$h_1$ : height of closest phase, m

K : 3 for 750kV class =3.5 for others, gradient limit 15-19$kV/cm$

$m_0$ : Irregularity factor (0<$m_0$≤1)

=1 for smooth, polished solid, cylindrical conductors= 0.93-0.98

For weathered, solid, cylindrical conductors= 0.87-0.90

For weathered conductor with more than seven stands= 0.80—0.87
For weathered conductor with up to seven stands.
$m_p$ : Irregularity factor for visual corona ($0<m_p\leq 1$)
=1 for smooth, polished, solid, cylindrical conductors =0.93-0.98
For local and general visual corona on weathered, solid, cylindrical conductors=0.70-0.75
For local visual corona weathered stranded conductors=0.80-0.85
For general visual corona on weathered stranded conductors.
p : barometric pressure in cm of mercury
$p_0$ : fair weather corona loss per phase or conductor
R : lateral distance from antenna to nearest phase, m
RI : radio interference, in decibels (quasi-peak) above $1\mu V / m$ at 1MHZ and at standard reference location of 15m laterally from outermost phase.
r : radius of conductor, cm
TVI: television interference, in decibels (quasi-peak) above $1\mu V / m$ at a frequency f, MHz.
t:ambient temperature in degrees Celsius.
$u_i$: mean value of the random variable, xi
V : line-to-neutral operating voltage KVs.
$V_O$: disruptive critical voltage to neutral, kVs (rms)
$V_V$ : visual critical voltage, kV (rms)
$X_i$ : $i^{th}$ random variable.
$\boldsymbol{\alpha}_i$ : percent tolerance in the random variable, xi
δ: air density factor
Φ: Frequency in MHz
**Σi:** standard deviation of the random variable, $X_i$