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The phenomenon of corona and its effect on the transient wave in the transmission line

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Abstract: Corona effect has been considered as a source of substantial loss due to High Voltage AC Transmission lines. This paper presents a comprehensive account of development of a mathematical model for the Corona Effect which is designed based on the Peek's equation. The scope of this work is determining the corona power losses dependent on conductor's diameters. The simulation is completed using the corona model for 220 kV overhead transmission lines which were developed by Matlab/toolbox (release 2010). The corona effects analysed in high voltage transmission lines, and factors of decreasing the corona losses have been identified. Factors such as increasing the diameter of conductors those lead to increase the critical disruptive voltage. The paper describes the analytical approach, computational tools and simulations models.

Keywords: (Power Losses, Transmission Line, Electric Field, Corona Models, Critical Disruptive Voltage)

Introduction

In transmission lines, corona effect causes power loss, audible noise, electromagnetic interference, purple glow, ozone production, etc. Hence to minimize this negative effects, conductor surface condition, size, distance to ground and other conductors have to be considered when planning and construction of overhead power lines . In transmission of electricity ac voltages are used to transmit electric power because of their efficiency against dc voltage. The basic difference between ac and dc coronas in the periodic change in direction of the applied field under ac, and its effect on the residual space charge left over from the discharge during preceding half-cycles. In a ac corona tracheal pulses, negative glow and positive glow and streamer coronas can be observed. This study investigates the effect of ac corona on different type and size of conductors. In order to obtain an ideal corona cage is built. Tests are performed on aluminium, copper and steel conductors. For each bare conductor, the corona inception voltage, extinction voltage and currents at this voltage levels are reported. Moreover, corona power loss is calculated by using common experimental formulas. This work also provides a discussion of corona and induced current effects associated with operation of the proposed high-voltage transmission lines. These effects include audible noise, radio, television, computer monitor interference, gaseous effluents, fuel ignition, and interference with cardiac pacemakers. Since these effects are common to all transmission lines, they have also been investigated generally application. These effects have been assumed to be negligible or non-existent. Due to that, they don't have significant influence on the outcomes and mitigation measures are not required.

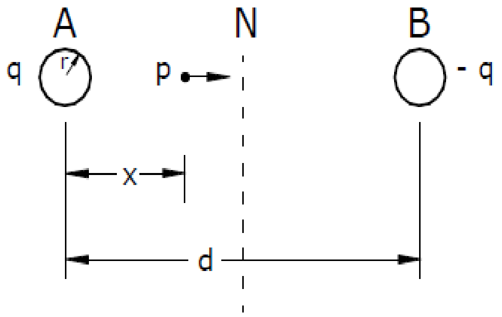
I. Corona in transmission line

The phenomenon of corona plays an important role in the design of an overhead transmission line. Therefore, it's profitable to consider the following terms much used in the analysis of corona effects.

II. Critical disruptive voltage:

If one-phase transmission line as shown in Fig(1). Let r assume that a represents the radius of each conductor and d is distance between the conductors such that d >> r. In this single-phase transmission line, let consider q is the charge per unit length on one of the conductors and hence – q on the other.

If the operating voltage is U, the potential of conductor A with respect to neutral plane N will be U/2 and that of conductor B will be -U/2.



Fig(1) 1-phase transmission line

The electric field intensity at P due to the both line charge will be represented as follows:

$$E_x = \left(\frac{q}{2\pi\varepsilon 0 x}\right) - \left(\frac{-q}{2\pi\varepsilon 0(d-x)}\right) \quad \text{v/m} \quad (1)$$

$$E_x = \frac{q}{2\pi\varepsilon 0}\left(\frac{1}{x} + \frac{1}{d-x}\right) \quad (2)$$

The potential different between the conductors can be writing by the following formula :

$$U = -\int_{d-r}^{r} E_x = \frac{q}{\pi\varepsilon 0}\ln\frac{d-r}{r} \quad (3)$$

Since r is very small as compared to d, d −r =d . Substituting for q from the above equation

$$q = \frac{\pi\varepsilon_0 U}{\ln\frac{d}{r}} \quad (4)$$

$$E_x = \frac{U'd}{x(d-x)\ln\frac{d}{x}} \quad (5)$$

Where U' is the line to neutral voltage of the system.

Critical disruptive voltage can be simply defined as the voltage at which complete disruption of dielectric occurs. This voltage corresponds to the gradient at the surface equal to the breakdown strength of air. This dielectric strength is denoted by go and is equal to 30kV / cm peak at NPT i.e., 25C° and 760 mm OF Hg. At any other temperature and pressure

$$g_o' = g\delta \quad (6)$$

Where is the air density correction factor and is as following:

$$\delta = \frac{3.92 * b}{273 + t} \quad (7)$$

Therefore, the critical disruptive voltage is given by:

$$U_o = r g_o \delta \ln\frac{d}{r}. \quad (8)$$

For high voltage transmission line the ACSR conductors are used. The cross-section of such conductors a series of arcs of circles each of much smaller diameter then the conductor as a whole. The potential gradient for such conductor will be greater than for the equivalent smooth conductor. The irregularities on the surface are increased further because of the deposition of dust and dirt on its surface and the breakdown voltage is further reduced. Average value for the ration of breakdown voltage for such conductor between a smooth conductor lines and 0.85, and is denoted by mo. The final expression for the critical disruptive voltage after taking into account the surface of the conductor is given by:

$$U_o = r g_o \delta m_o \ln\frac{d}{r} \quad [KV] \quad (9)$$

mo =1 for polished conductor (smooth conductor).

=0.98→0.92 for dirty conductor.

=0.87→0.80 for stranded conductor.

III. Corona loss

In high voltage transmission line when the applied voltage exceeds a critical disruptive value, the thin layer of air around the transmission line ionizes. This ions result in space charges which move round the conductor. To remain the charges in the motion required the energy derived from the supply system. In order to maintain the flow of energy over the conductor it is necessary to supply this additional loss from the supply system. This additional power is referred to as corona loss. Peek's has been previously studied the effect of various parameters on the corona loss and he deduced an empirical relation:

$$P = 241 * 10^{-5} * \frac{(f+25)}{\delta} * \sqrt{\frac{r}{d}} * (U_P - U_0)^2 \quad kw/km \quad (10)$$

Where

P = corona power loss.

f = supply frequency .

δ = air density factors .

U_p = Phase- neutral voltage.

U_o = disruptive voltage (r. m .s) per phase.

r = radius of the conductor (cm).
d = spacing (or equivalent spacing) between conductor (cm).

In overhead transmission line the following factors affect corona los:
(i) electrical factors.
(ii) atmospheric factors and.
(iii) factors connected with the conductors.

i. Electrical factors:

Referring to the equation (9) it can be notified that the corona loss is a function of frequency. Thus higher values for both or the frequencies of supply and the losses due to corona. This means that dc. corona loss is less as compared with a.c. corona loss. This is because during the corona phenomenon of a.c. the value or always produces third harmonics and hence frequency is not exactly 50 Hz but it also contains a third harmonic component.

ii. Atmospheric Factors:

Atmospheric factors consist in air density and weather condition. Air density affects the generation of corona sources as demonstrated by Peek empirical equation (9). From this equation the losses are a function of air density correction factor ∂. The lower value of ∂ causes higher loss, because it appears directly in the denominator of the equation and indirectly in the value of critical disruptive voltage [2,3,11].

$$U_o = 21.2 * m_o * \delta * \ln\frac{d}{r} \qquad (kv) \quad (11)$$

For the lower value of δ, losses will be higher, because the lower value of δ will have the lower value of U0 and hence higher value of $(U - U_O)^2$, where U is the operating voltage in kV. During the bad weather conditions such as rain, snow and hailstorm will diminish the critical disruptive voltage and hence increase the corona loss. These is due to the fact that rain droplets on the transmission line conductors can be viewed as sharp edges which enhances the electric field and therefore reduces the corona disruptive voltage and hence increase the corona power loss. Corona generation increases whenever moisture accumulates on the conductor. Conductor current, if it heats the conductor, will be discouraged the formation of water drops during fog and during high humidity. However, it has little effect during heavy rain and snow. Corona loss observations in the operating lines during the hoarfrost have shown that the highest corona losses occur when hoarfrost accumulates on a cold conductor, during the night time hours, when load currents are not sufficient to warm the conductors enough to melt the hoarfrost [1,3]. Wind speed has been found to have a very small effect on corona generation unless the wind is blowing particles onto conductors.

iii. Factor connected with conductors:

This factor can be divided into three categories:

1- Conductor surface conditions.
2- Conductor diameter.
3- Number of conductors.

The conductors are exposed to atmospheric conditions; the surface would have dirt.
Deposited on it which will lower the disruptive voltage and increase corona loss. Audible noise is primarily a foul-weather phenomenon therefore conductor-surface conditions are only important inasmuch as they influence water drop formation. From the equation (9) for corona loss, it can be observed that the conductor size appears in two places, it's worth mentioning that the other parts of equation (9) are assumed to be constant, so:

$$P = K\sqrt{\frac{r}{d}}(U_P - U_O)^2 \qquad \frac{kw}{km} \qquad (12)$$

Equation (12) shows that the first losses are proportional to the square root of the diameter of the conductor, if the diameter of conductor is large, then the loss will also be large. Secondly, since U_0 is approximately directly proportional to the diameter of the conductor, hence the large size of the conductor leads to the critical disruptive voltage has to be large and hence the difference between the operate and critical disruptive voltage will be small. Number of conductors is an input into the calculation of the electric field at the surface of conductors. For operating voltage 200 kV and above it, is found that one conductor per phase gives large corona loss and hence large radio interference (RI) level which interferes with the communication lines which are normally run parallel with the power lines. Most research has shown that the RI does not increase with the number of conductors for a fixed conductor diameter[3,4].

The higher the corona losses in the power transmission lines with one conductor is solved with by using two or more than two conductors per phase or as they are known as bundling of conductors. By bundling the conductors the self geometric mean distance (GMD) of the conductors is increased thereby; the critical disruptive voltage is increased and hence corona loss is reduced [1,7,9].

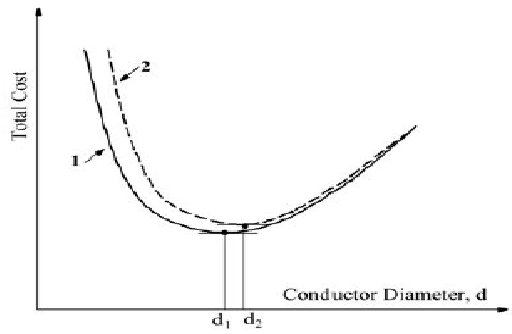
To reducing corona loss can be used following methods:

- large diameter of conductors.
- hallows conductors.
- bundled conductors.

With the aim to reduce the corona power losses, have been made experiments and research how affects have the larger diameter and bundled conductors.

If conductor radius is larger, surface field intensity is less and hence corona losses are lower. For the same current carrying capacity, an ACSR conductor has larger radius, therefore the transmission lines with ACSR conductors have lower corona loss. Also, for bundled conductors lines effective radius is larger and hence corona loss is less.

Corona losses do not generally play an important role in the overall design of transmission lines. With most computer programs that evaluate only the cost of resistive losses in overhead transmission lines. But, there are conditions where corona losses may influence the economic choice of conductors, and compact lines may be one of those conditions. The cost of transmission line conductors, usually expressed in terms of an annualized cost, is made up of the annualized cost of capital investment and the annual cost of energy losses incurred during the operation of the line. The capital cost is almost directly proportional to the conductor cross-section, or to d_2, where d is the conductor diameter. In the absence of corona on conductors, the energy losses consist mainly of the resistive or I^2R losses, where I is the load current flowing through the line, and R is resistance of the conductor. Insulator leakage losses are generally negligible compared to the resistive losses. The economic choice of conductors, for a given transmission voltage and load current, involves minimizing the total annualized cost of conductors over the expected life of the line. Since the capital losses decreases with d, there is an optimum value of d for which the total cost attains a minimum [6,7,8]. In Figure(2), curve 1 shows the variation of the total cost as a function of conductor diameter d. Minimum total cost is obtained for an optimum conductor diameter d_1. For conductor sizes either lower or higher than d_1, the total cost will be higher. The increase in total cost may become important for lower load currents and/or higher energy costs [5,10,11].



Fig(2) Economic choice of conductors

In the presence of corona on conductors, the mean annual corona losses should be added to the resistive losses to determine the annualized the energy losses. As in the case of resistive losses, corona losses decrease as d increases. This is illustrated by curve 2 of Figure 2, which differs from curve 1 at lower values of d and merges asymptotically with curve 1 for the increased value of d. The minimum total cost of curve 2 occurs at a slightly larger diameter d_2. With the increasing cost of energy, studies carried out in several countries have shown that it is important to take into account the cost of corona losses in the economic choice of conductors particularly for lightly loaded or compact transmission lines in the range of 220–400 kV, lines in traversing regions of high altitude or of extreme pollution, and also for normally loaded lines at voltages above 750 kV [3,5,11].

A. Modeling Of Corona Effect

Since the project is studying the Corona effects in AC transmission lines, the most reliable mathematical equation to simulate the losses is the famous Peek's equation. Peek studied the corona effects and all factors that contribute to all noticeable changes along the transmission lines. An extended empirical peek's equation is presented to compare all variables [7,10]

$$\mathrm{p} = 241 * 10^{-5}\ \frac{(f+25)}{\delta}\sqrt{\frac{r}{d}}(U_{\mathrm{p}} - U_0)^2\ kw/km.$$

P is the Corona power loss in kw/km , f is the system frequency, δ is the air density factor, r is the radius of the conductor in cm, d is the distance of two parallel conductors, Up is the applied voltage (line to neutral) in KV and Uo is the disruptive voltage of the Corona[2,9,10].

B. Matlab Simulink Model

To study all calculations and all factors manipulation, Matlab tool Simulink is used. Simulink is an easy tool to monitor the output change with respect to each element adjustment. A scope will be put on the output to plot it clearly with all changes.

The sub blocks involved in the design are represented in Fig.3.The sub block has realization of all the factors on which the corona effect depends upon through Peeks equation.

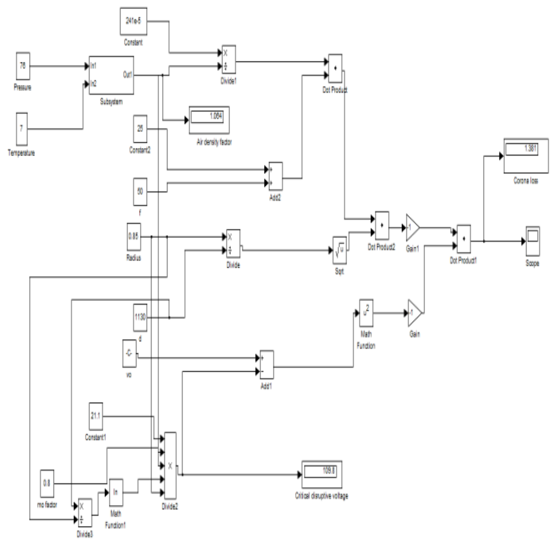


Fig (3): Computational Schematic of Corona Model

$$\delta = \frac{3.92*b}{273+T(°C)}$$

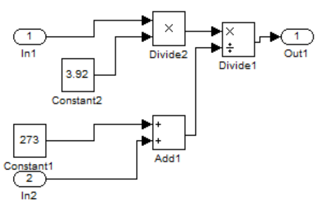


Fig (4): subsystem the air density correction factor

C. Radius Of Conductor Effect On Corona

Could be hallow cable or steel core cable which is relative to radius Conductor Radius is considered to be the most valuable factor in evaluating Corona and also the key point in commercially and economically designing the transmission system. Beside the material of the cable and type, a bigger radius leads to bigger surface area and less field intensity. As a result, Designers tend to be very careful in choosing the size of the cable (sometimes the type because it).

Table(1) corona and disruptive voltage value when Radius of Conductor changes

R (cm)	Critical disruptive voltage kv/ph	Corona loss (kw/km/Ø)
0.76	116.5	0.5256
0.77	117.8	0.4042
0.78	119.2	0.2983
0.79	120.5	0.2081
0.80	121.8	0.1337
0.81	123.1	0.07576
0.82	124.4	0.03372
0.83	125.7	0.008469
0.84	127.00	1.059e-9

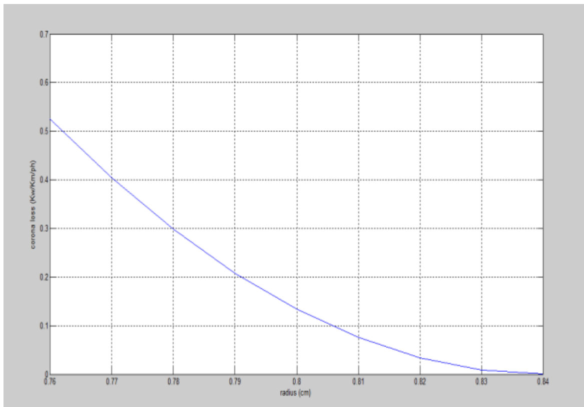


Fig (5): Corona Losses at 220 KV.conductor radius

D. Conductor Distance

Another important factor would be the distance of the parallel conductors as they tend to affect each other through electrostatic energy or electromagnetic energy. As a result, more energy will be given to surface electrons that will knockout more air ions and produce more loss. We took the case of 220kv system with 0.84 cm radius cable and increase the distance gradually and the result is shown in figure 6. And as expected, the corona losses decrease as the distance increases and almost disappear when the distance reaches 10.90 meter. Changing the distance between conductors is done through the transmission lines poles, because their structures define the distances among all lines.

Table(2) corona and disruptive voltage value when Radius of Conductor changes

D (m)	Critical disruptive voltage (kv)	Corona loss (kw/km/Ø)
10.4	126.2	0.003561
10.5	126.4	0.002247
10.6	126.5	0.001247
10.7	126.7	0.000547
10.8	1.26.9	0.0001352
10.9	127	1.059e-9
11	127.2	0.0001301

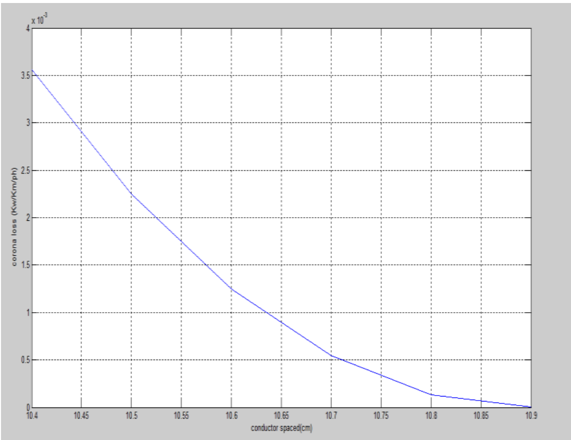


Fig (6): Corona Losses at 220 KV Line vs. distance between conductors

E. Irregularity Factor: is a factor that loses its properties over time in the beginning dose note significantly affect the loss power but when a surface reaches the roughness state most of the transferred power is lost in the loss of the corona.

Table(3) Corona and disruptive voltage value when Irregularity factor changes

Mo	Critical disruptive voltage kv/ph	Power loss kw/km
1	127.00	1.059e-009
0.98	124.5	0.0324
0.96	121.9	0.1296
0.94	119.4	0.2915
0.92	116.9	0.5183
0.90	114.3	0.8098
0.88	111.8	1.166
0.86	109.2	1.587
0.84	106.7	2.073
0.82	104.2	2.624

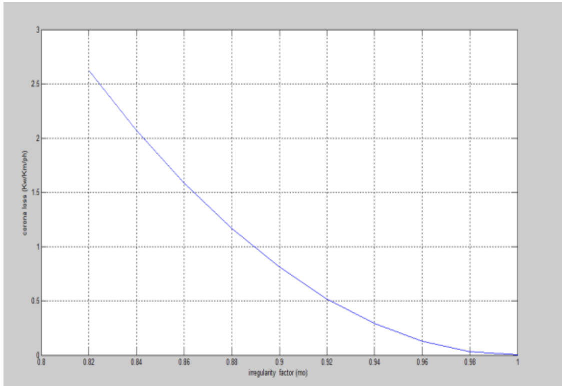


Fig (7): Corona Losses at 220 KV Line vs. Irregularity factor conductor

F. Temperature

Temperature factor plays a small role in corona loss and also it is something that practically cannot be changed. However the figure (8) shown below will examine the influence of changing temperature range, 4 to 48C^o degrees Celsius.

Due to the weather effect in corona loss, in fair weather the factor will be considered 1 that will lead to normal disruptive voltage value. On the other hand, since humidity, rain and snow weather affects the corona power loss directly which could lower U_o to as low as 80%. This is natural factor and unpredictable, so for designers worst condition with bad weather is considered.

Table(4) corona value when temperature changes

Temperature (C^o)	Critical disruptive voltage (kv)	Corona loss (kw/km/Ø)
48	117.9	0.4478
45	119	0.3418
42	120.2	0.2493

39	121.3	0.1707
36	122.5	0.1064
33	123.7	0.06585
30	124.9	0.02243
28	125.8	0.00813
25	127.00	1.059e-9
22	128.3	0.008284
19	129.6	0.03349
16	131	0.07614
13	132.3	0.1368
10	133.7	0.216
7	135.2	0.3144
4	136.6	0.4326

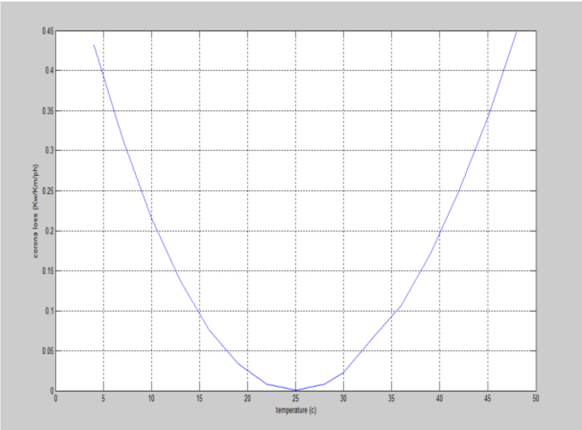


Fig (8): Corona Losses at 230 KV vs. Temperature

G. Types Of Conductors

Transport line 220kv extends in Libya from the middle of several areas where temperatures vary from region to region, in the following tables the best designs for the 220kv transmission line contain the lowest corona losses according to temperature change from 44C° to 7C°, these designed in terms of diameter of the conductor and the distance between the conductor can match the specifications of the transmission line previously established in Libya , if we did not get exact parameters for this line, but these designs were carefully selected. So we can know value the corona loss and that by the temperatures and diameter of the conductor and the distance any blasé in Libya.

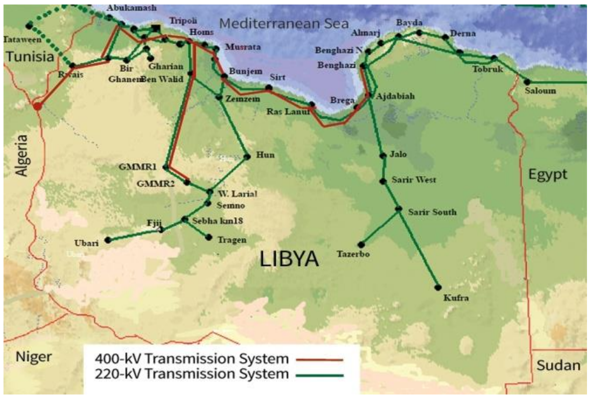


Fig (9): distribution of transmission lines 220kv and 400kv in Libya

1 Conclusion

Various factors affecting corona loss play a vital role in the prevention of corona. Among those factors some are natural and some are equip mental factors in which we cannot fully control the natural causes but we can take certain measures. All model results were in line with theory expectations with regards to each factor effect on corona loss. Peek's equation based model has proven to be affect to all variables studied in this work and the reliability is high when inputting reasonable values for all.

In the temperate atmosphere (25 C° and 760mmhg), the best measurements in line with the design of the 220 kv transmission line are (D=1090cm and R=0.84cm). when the transmission line is detected in high-temperature areas, the distance between the conductor must be increased as showing in types of conductors. Corona power can be acceptable to a certain level but yet it should always be considered while designing the transmission system beside resistive power loss calculations.

Moreover, economical study has to be on estimating the optimal parameters for all the system to utilize best reliable delivered power with least cost as this is the deal goal from engineering perspective. Full awareness of corona effects should be passed on to all industries dealing with power energy transmission. Yet, the corona phenomenon brings a great usage to some applications and further researches and studies should focus on this field.

References

[1] Philip Koshy panicker - "Ionization of air by corona discharge" The University of texas at Arlngton August 2003.

[2] Muhammad Ahmed Dawood[1], Dr. Ghous Buksh Narejo[2] "Modeling of Corona Effect in AC Transmission Systems" ISSN 2229-5518.

[3] Dr jp holtzausen[1] , Dr wl vosloo[2] - "High voltage engineering practice and theory" - ISBN: 978 - 0 - 620 - 3767 - 7.

[4] Isuf Krasniqi[1] , Vjollca Komoni[2] - "Corona Losses Dependence from the Conductor Diameter" , ISBN: 978-1-61804-041-1.

[5] D. Das - "Electric Power System" ISBN (13): 978-81-224-2515-4.

[6] Prof. Dr. ahdab Elmorshedy "High voltage engineering" .

[7] F.W. Peek, "Dielectric Phenomena in High Voltage Engineering" , McGraw-Hill, 1929.

[8] N.H. Malik, A. Al.Qureshi, M.I. Qureshi, "Electrical Insulation in Power Systems" , 1st ed., Marcel Dekker, New York, 1998.

[9] Abdulate.A.M.ELGANAI "The Corona Effect on High Voltage Transmission Lines" . IJSETR International Journal of Scientific Engineering and Technology Research, ISSN 2319-8885 Volume.08, Jan-Dec-2019, Pages: 29-31.

[10] Abdulate.A.M.ELGANAI "Corona Losses Reliance from the Conductor Diameter Developed in Matlab/Simulink". IJSETR International Journal of Scientific Engineering and Technology Research, ISSN 2319-8885, Volume No.07, Issue No.12, December-2018, Pages: 1989-1993

[11] M. Khalifa, High-Voltage "Engineering, Theory and Practice" , Marcel Dekker, Inc., New. York, 1990.