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The Effect of the Corona Discharge Process on High-Voltage Power Transmission Lines

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Abstract. When the voltage gradient (electric field intensity) in an insulation system exceeds its critical value, a local dielectric breakdown process begins in the air surrounding the conductors of a high-voltage transmission line. In this case, under the influence of a high-energy electric field, air molecules undergo electron-ionization (ionization), meaning that free electrons are released and positive ions are formed. This process is referred to as transient gaseous ionization, and it leads to the occurrence of partial discharges. The resulting partial discharges do not cause complete dielectric breakdown of the insulation; however, they initiate local electrical, thermal, and chemical degradation processes within the insulating material.

INTRODUCTION

The corona phenomenon reduces the reliability of the insulation system, leads to the degradation of the insulating material, and may ultimately cause the failure of the entire system due to dielectric breakdown. The significance of this study lies in the fact that the parameters characteristic of the corona process in high-voltage transmission lines have a negative impact on electrical power losses. This necessitates a thorough analysis of these parameters and the development of effective measures to minimize their adverse effects [1].

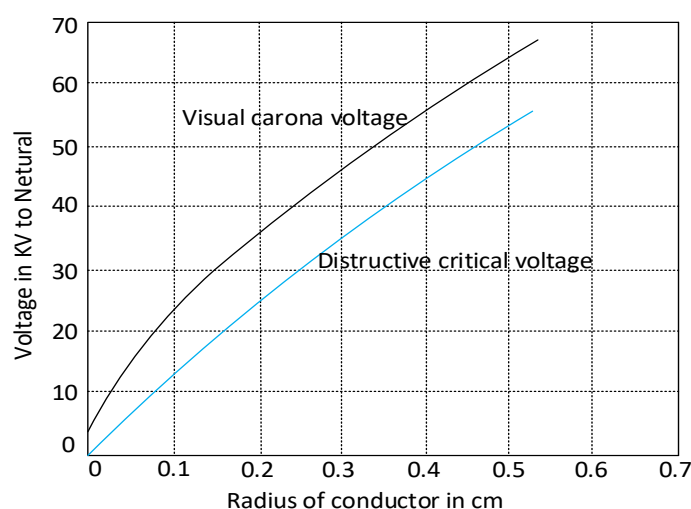


FIGURE 1. Corona onset voltage at different conductor radius.

The power loss due to corona discharge is inversely proportional to the distance between the conductors. If the spacing between the conductors is chosen to be sufficiently large, corona losses can be almost completely eliminated [2-5].

EXPERIMENTAL RESEARCH

The power loss due to corona discharge depends on the air density correction factor-the higher this factor, the lower the corona loss. Under conditions of low atmospheric pressure and high temperature, the critical breakdown voltage decreases, leading to a greater likelihood of corona discharge and associated power losses [6].

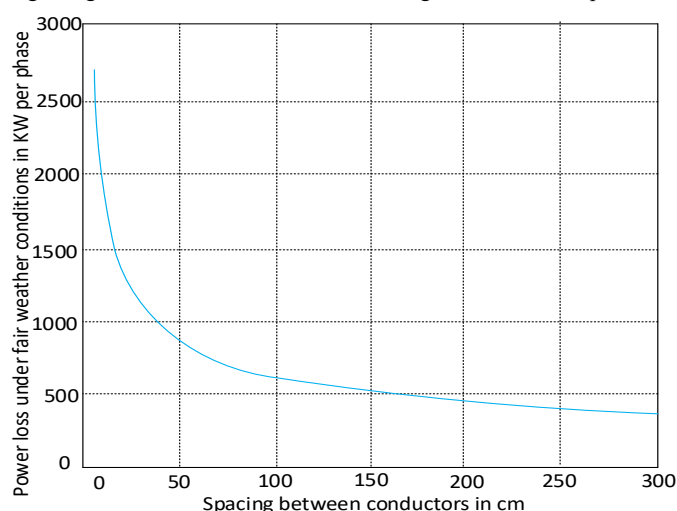


FIGURE 2. Dependence of power losses caused by corona discharge on the distance between conductors.

RESEARCH RESULTS

Under cloudy or adverse atmospheric conditions-such as snowfall, rain, or stormy weather-the disruptive critical voltage decreases, resulting in an intensification of corona effects.

TABLE 1. Total and component parts of electrical energy losses

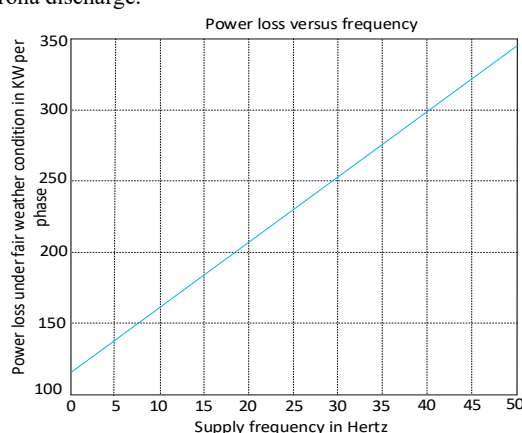
Losses under overload conditions, %	64
Losses due to the corona effect, %	20
No-load losses of the power transformer located at the substation, %	8
Losses in the reactor block located at the substation, %	2
Total losses in measuring transformers and high-voltage surge protection devices, %	3
Total losses in capacitor installations, %	3

In determining and analyzing losses in electrical networks, several factors are taken into account. Corona losses are based on power losses per unit of capacity and the duration of various weather conditions during the calculation period. At the same time, periods of fair weather (for the purpose of calculating corona losses) are considered as those with relative humidity below 100% and the presence of ice coating.

TABLE 2. Average annual values of power losses due to the corona process

Voltage, kV	Number of conductors per phase	Cross-Sectional area of the conductor	Conductor radius, mm	Losses, W/m		Relations P_2/P_1
				According to P_1	According to P_2	
1150	8	330/39	12	32	49,5	1,5
750	5	240/56	11,2	13	25	1,9
500	3	330/43	12,6	9	11,6	1,3
330	2	300/39	12	3.8	4	1,05
220	1	300/39	12	1.6	2	1,25

The corona process in overhead power transmission lines generates third harmonic components, which further increase power losses due to corona discharge.

**FIGURE 3.** Frequency dependence of power losses

The corona process begins at voltages exceeding the critical breakdown voltage. Power losses due to the corona process vary over a very wide range, corresponding to a second-order behavior, and their temporal changes can sometimes occur very rapidly. Therefore, periodic measurements carried out at experimental sites do not provide reliable values for average and maximum corona losses. To accurately determine the characteristics of corona losses, it is necessary to have data on continuous variations of weather parameters and corona losses over a solar activity cycle (10–12 years), since the cyclical recurrence of meteorological events is determined precisely by this period of solar activity. Within this period, corona losses can be considered a stochastic process, with their characteristics defined by a distribution function and a correlation function. Corona losses are the energy losses that occur during the transmission of electrical energy as a result of the formation of corona charge, which is a characteristic form of independent gas charges arising in sharply non-uniform electric fields. In alternating current transmission, the insulation system serves to increase the reliability of power supply systems and reduce losses during energy transmission. However, under certain adverse weather conditions- especially rain, wet snow, fog, and icing, which lead to significant energy losses -the onset voltage of corona decreases, resulting in the occurrence of overall corona phenomena. For nominal voltages of 500 kV and above, it is advisable to use conductors with a larger diameter but smaller cross-sectional area to reduce energy losses due to corona [7-19].

For a 500 kV overhead power transmission line, under rainfall intensity of 1 mm/h, the annual duration of rain in the transmission area is 401 hours. The creation of smart electrical grids is not feasible without complete and targeted monitoring of their condition. The primary goal of managing electrical power networks is to save energy and ensure the reliability of electricity supply. One of the most effective ways to address energy savings is to optimize the operating modes of power systems in terms of voltage and reactive power coefficients. Therefore, the optimal voltage level at energy system nodes depends on the ratio between corona losses and load losses. Under fair weather conditions, load losses prevail over corona losses, whereas in adverse weather (snow, rain, icing), corona

losses can increase by 1–2 times. For the line under consideration, corona losses under fair weather conditions amount to 1200 kW.

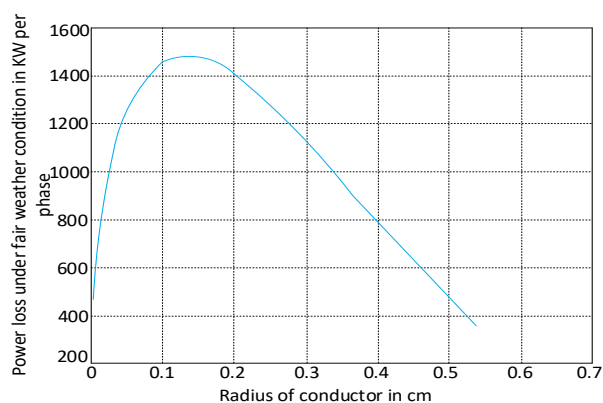


FIGURE 4. Graph of changes in power losses due to corona relative to conductor diameter (or cross-sectional area).

The maximum error of electrical measuring devices in determining corona losses is 229 kW, which constitutes 19% of the corona power loss under fair weather conditions. Previously, the operating mode of individual transmission lines was considered. When analyzing the power system as a whole, it is necessary to account for losses across all lines in the region. Therefore, in calculating optimal voltage levels at system nodes, corona losses and load losses across all transmission lines in the considered energy area must be taken into account. When corona losses in the lines are minimal—that is, under fair weather conditions—increasing the network voltage is advisable. This measure can reduce power losses in the network by approximately 7.5 MW, which corresponds to 5.1% of the total losses. Furthermore, if a controlled shunt reactor is installed instead of a fixed shunt reactor, the effectiveness of optimization increases by an additional 6.5%, reaching a total of 8 MW. Calculations for optimizing the line operation by regulating voltage, without considering voltage limits, showed the following: under fair weather conditions, corona losses are minimal, and the optimal line voltage is significantly higher than the operating voltage—approximately 1.2–1.25 times greater.

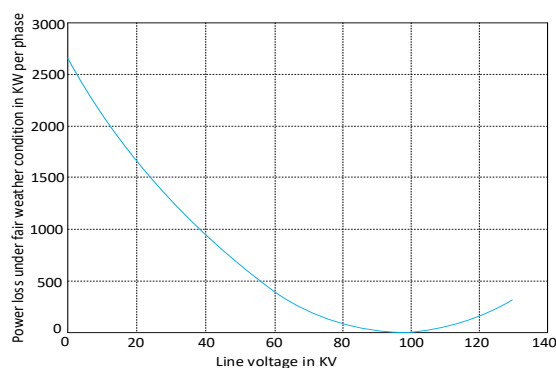


FIGURE 5. Dependence of corona losses on line voltage

The results indicate that voltage levels improved at all substations. Factors such as distance from power generation points, variations in demand, weather conditions, and unbalanced loads on distribution transformer phases, the complexity of the energy system for transmitting electricity to the point of use, consumer behavior, and the use of electronic equipment contribute to a reduction in the quality of the delivered electrical energy.

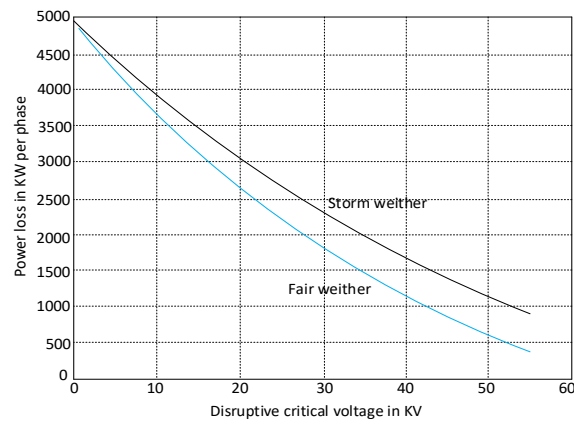


FIGURE 6. Graph of power losses due to corona under stormy and fair weather conditions

This also involves studying and improving the methods for determining instantaneous power losses in corona and conductors, taking into account their measurement errors. Currently, a number of methods and analyses exist, and it is particularly important to assess the sensitivity of methods used to measure low-magnitude corona losses under high-humidity conditions, as well as conductor losses, in real-time operation of high-voltage overhead transmission lines.

TABLE 3. Indicators for calculating the optimal voltage to minimize losses in the supply line

Accumulated incremental losses due to corona, hours	2,33
Average voltage at the end of the line, kV	750,04
Average active power at the end of the line, MW	656,03
Average reactive power at the end of the line, KVar	147,09
Average active power due to corona, MW	14,65
Average loan losses, MW	10,49
Total active power losses in the line, MW	25,14
Average optimal voltage at the end of the line, kV	627,45
Total voltage losses in the line, kV	21,60
Total power drop in the line, MW	3,54

The assessment of instantaneous, daily average, and annual average electrical energy losses in high-voltage overhead transmission lines, as well as the calculation of power losses due to corona, allows for the development of technologies to integrate these results into systems designed to analyze and optimize the stable operating modes of power networks.

CONCLUSIONS

In conclusion, the measurement results demonstrate the possibility of determining the components of electrical energy losses in real time (load losses, corona losses, and power losses). This enables the optimization of operating modes in high-voltage overhead lines to reduce losses and achieve significant energy savings. Moreover, it has been proven that optimization of the system operation based on voltage levels cannot be performed without taking into account the current corona power losses. The results of the study can be summarized as follows:

1. The algorithm for calculating instantaneous losses during the corona process, when applied in the long-distance integrated computational software complex, is not sensitive to corona losses under high humidity conditions. Therefore, it is proposed to introduce corrections into the software algorithm to account for the above-mentioned losses.
2. Analysis of errors in determining corona losses through the algorithms of the long-distance integrated computational software complex demonstrated the advisability of applying a more accurate formula that considers the wave characteristics of overhead lines when calculating load losses in conductors of long transmission lines.

3. To account for the effect of voltage fluctuations on corona power losses in transmission lines longer than 250 km under fair weather conditions, the software algorithm was updated with a correction coefficient dependent on active and reactive power.

4. Calculation results for 500 kV high-voltage overhead transmission lines showed that the largest error in determining load losses arises from inaccuracies in measuring conductor temperature. The proportion of this error relative to the total loan losses is 4%.

5. The results indicate that in a 500 kV substation network, replacing fixed shunt reactors with controllable shunt reactors can increase the effectiveness of operational mode optimization by an average of 10%.

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