



Research Article

Comprehensive Monitoring and Intelligent Diagnostics Using Multifactor Assessment of Corona Losses to Improve Energy Efficiency in High-voltage Overhead Transmission Lines

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Abstract

This paper investigates the monitoring and mitigation of electrical energy losses caused by corona discharge in high-voltage overhead transmission lines. The relevance of the study is associated with the growing need to improve the energy efficiency of power networks, reduce technical losses, and ensure the reliable operation of power supply systems under increasing electrical loads and more complex operating conditions. A detailed analysis of the factors affecting corona discharge intensity is carried out, including operating voltage levels, conductor design characteristics, surface conditions, meteorological influences, and environmental parameters. A comprehensive approach to continuous corona monitoring is proposed based on the integrated utilization of electrical, electromagnetic, and meteorological data. The potential of modern digital technologies for real-time condition assessment of overhead transmission lines and forecasting of energy losses is examined. The impact of corona discharge on power transmission efficiency is evaluated, and key directions for loss reduction through improvements in transmission line design and operational practices are identified. The obtained results demonstrate that the implementation of continuous monitoring systems enables the timely detection of network sections characterized by increased corona activity, improves the accuracy of energy loss assessment, and supports the development of effective technical measures for loss reduction. The practical significance of the research lies in the applicability of the proposed approach to the modernization of high-voltage power networks aimed at enhancing energy efficiency, operational reliability, and the overall performance of electric power infrastructure.

Keywords

Corona Discharge, Corona Power Losses, Condition-based Monitoring, Energy Efficiency, Intelligent Monitoring Systems, Power Transmission Networks, Digital Power Systems, Smart Grid Technologies

1. Introduction

Corona discharge in high-voltage overhead transmission lines is accompanied by the ionization of the surrounding air,

which can reduce insulation reliability, accelerate the ageing of insulation components, and cause additional power and energy

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losses. This article examines an algorithm for calculating corona losses based on detailed line modeling, in which each phase conductor is analyzed as a separate element. This approach enables a more accurate assessment of the distribution of losses, the identification of the optimal configuration of bundled conductors, and the selection of appropriate spacing between sub conductors.

The results show that the number of sub conductors per phase, their geometric arrangement, the operating voltage level, and reactive power operating conditions significantly affect the magnitude and asymmetry of corona losses. Therefore, corona effects should be taken into account during both the design and operation of high-voltage lines. The article also substantiates the need to develop a dedicated measurement and assessment methodology that can reliably determine a line's operating condition under real-world conditions and quantitatively evaluate losses caused by corona discharge [1, 2].

Methodology for monitoring and assessing electrical energy losses caused by corona discharge.

Assessing instantaneous, daily average, and annual electricity losses in high-voltage overhead transmission lines, as well as integrating calculated corona-related power losses into analytical and optimization platforms for evaluating stable power-system operating modes, requires the development of a specialized technological framework. This framework should include an in-depth investigation of errors inherent in existing methods for determining losses associated with corona discharge and conductor current loading, followed by improvements to these methods to increase calculation accuracy. Although various analytical approaches and diagnostic methods are currently available, accurately assessing the relatively small electricity losses caused by corona discharge-particularly under conditions of high atmospheric humidity-and improving the sensitivity of methods for real-time measurement of conductor losses remain among the most pressing scientific challenges in the study of high-voltage overhead transmission lines. These methodological aspects play an important role in ensuring the reliability and efficiency of modern electric power transmission systems [3]. Moving any material object from one point to another inevitably involves certain costs. By contrast, electrical energy is unique in that, during transmission through power networks, a portion of it is consumed in the transmission process itself, without requiring additional external resources. Actual electricity losses are defined as the difference between the amount of electricity supplied to the network and the amount usefully delivered to end users. These losses comprise physical losses in network components during transmission, electricity consumed for the auxiliary needs of equipment installed at substations to support the transmission process, and commercial (non-technical) losses. [14, 15].

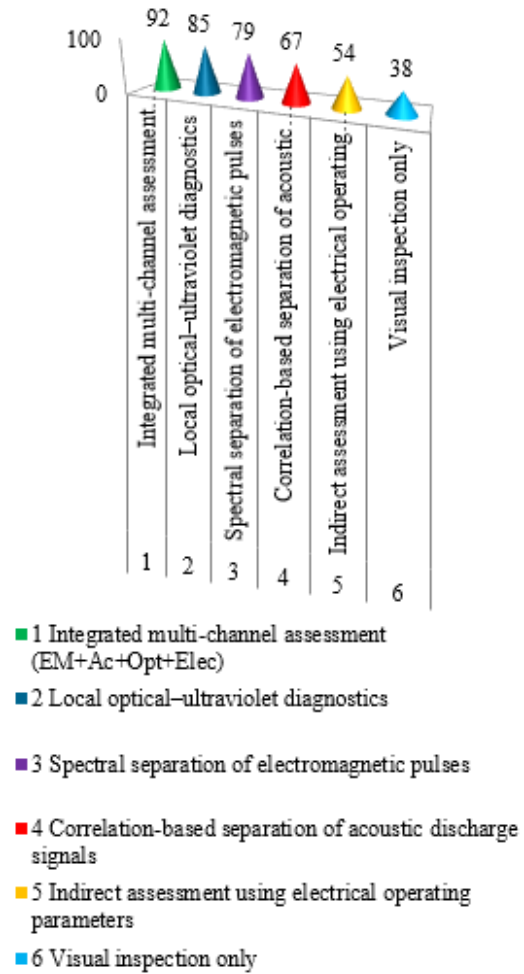


Figure 1. Dependence of corona losses on weather conditions and distance along the line.

The graph shows how corona power losses vary with distance along the line under different weather conditions. The curves indicate that corona losses are higher in foggy weather than in clear weather, owing to increased atmospheric humidity and intensified ionization processes near the conductor surfaces. Corona activity reduces the reliability of the insulation system, degrades insulating materials and may ultimately cause system failure due to dielectric breakdown. This study is relevant because the factors characterizing corona discharge in high-voltage transmission lines contribute to increased electricity losses. This makes it necessary to analyse these factors comprehensively and develops effective measures to minimize their adverse effects [4, 5]. To determine the conditions for corona discharge onset, the maximum electric field strength at the conductor surface is calculated using the following expression (1):

$$E_{max} = \frac{2U}{r \ln\left(\frac{D}{r}\right)} \quad (1)$$

Here (E_{max})-Maximum electric field strength at the conductor surface, kV/m, (U)- where U is the voltage, V; r is the conductor radius, in cm or m; and D is the average distance between phases, in cm or m. To account for atmospheric conditions, the relative air density is determined using the following expression (2):

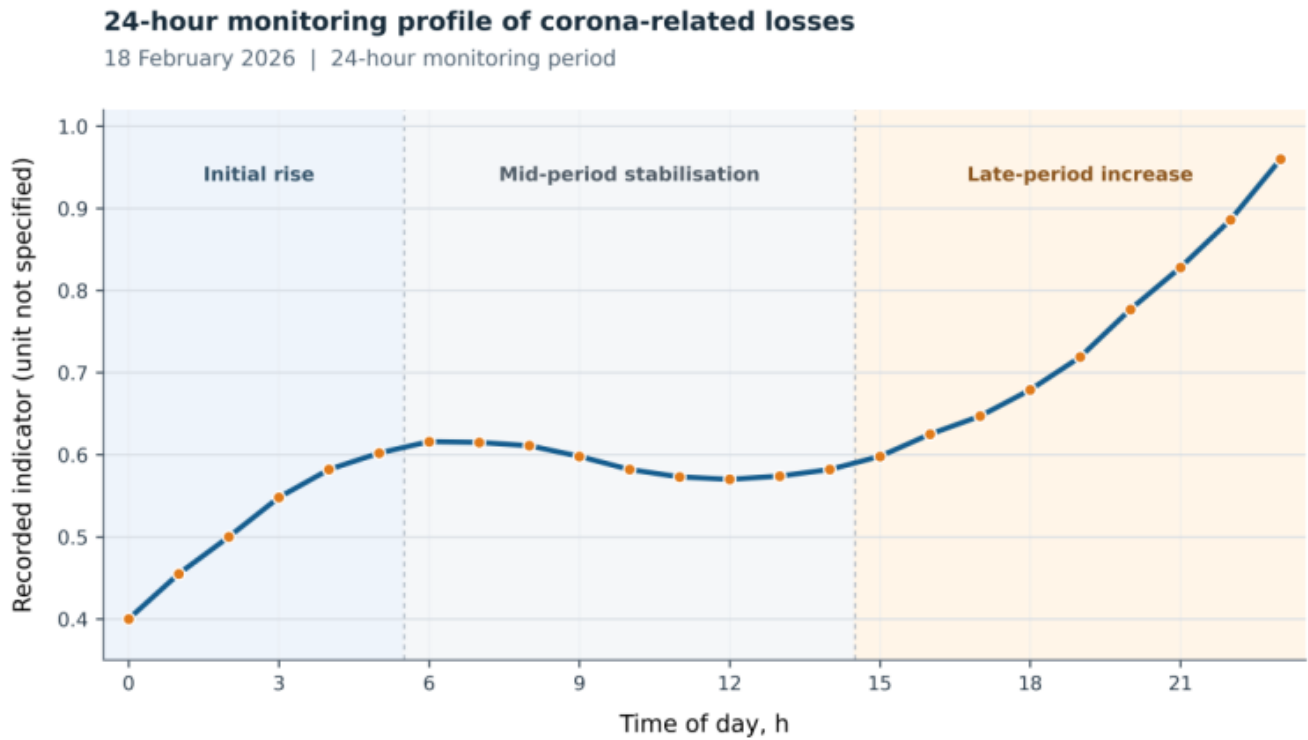
$$\delta = \frac{3.92p}{273+t} \quad (2)$$

where p is the atmospheric pressure, in Pa (mmHg), and t is the air temperature, in °C. This expression is used to determine the relative air density, which is important when assessing corona discharge. Air density varies with atmospheric pressure and temperature, directly affecting the dielectric strength of the medium surrounding the conductor. Based on monitoring data, relative power losses due to corona discharge were estimated using the following expression (3):

$$\Delta P = k \cdot E_{max} \cdot r \quad (3)$$

where k is an empirical coefficient accounting for the specific characteristics of the corona discharge process; for high-voltage overhead transmission lines, $k \approx 3 \times 10^{-12}$; ΔP_{cor} is the power loss caused by corona discharge, in W_{cor} kW; E_{max} is the maximum electric field strength at the conductor surface, in kV/m; and r is the conductor radius, in cm or m.

These mathematical expressions are used to process data obtained from monitoring systems and to analyses the combined effects of electric field strength, changes in conductor parameters, and atmospheric conditions on corona discharge. The results make it possible to identify patterns in the development of corona discharge on high-voltage overhead transmission lines and to provide a scientifically grounded assessment of measures aimed at reducing electricity losses.



Note: plotted values were estimated from the supplied image; raw measurements and the indicator unit were not provided.

Figure 2. Temporeal varigatin of coronaa losses based on monitoring data.

The graph is a generalized representation based on monitoring data and illustrates the relationship between relative air humidity and power losses due to corona discharge. Relative air humidity (%) is shown on the x-axis, and power losses due

to corona discharge (kW/km) are shown on the y-axis. The graph reflects the overall trend identified from actual observations [6, 7].

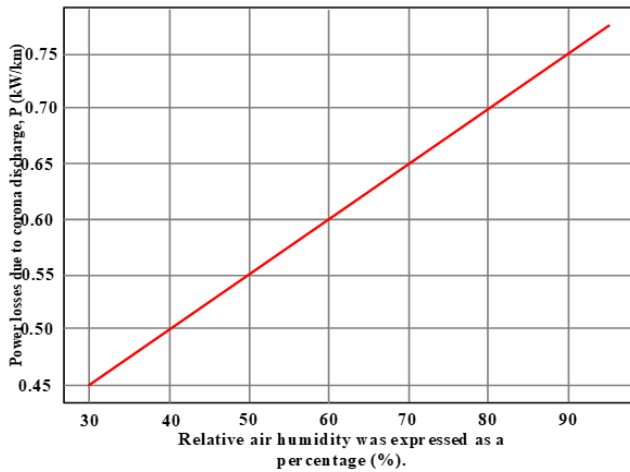


Figure 3. Relationship between humidity and corona losses based on monitoring data.

Based on experimental data obtained from the monitoring system, the distribution of power losses due to corona discharge was analyzed across different sections of the 220 kV overhead transmission line. The results show that corona losses are relatively higher in certain sections of the line under the influence of electric field strength and environmental factors. The monitoring system makes it possible to assess this process spatially. This relationship is presented graphically in Figure 4.

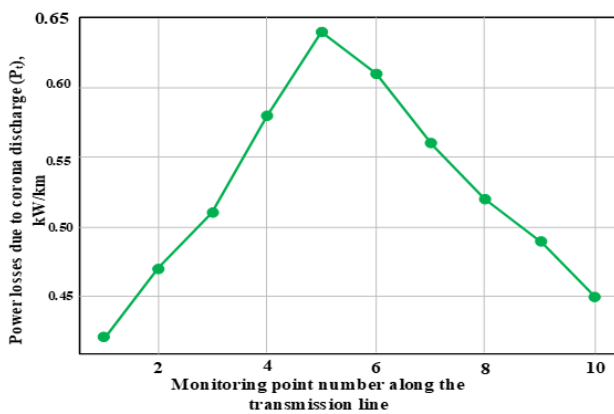


Figure 4. Distribution of corona losses in a 220 kV transmission line based on monitoring data.

The graph shows the distribution of power losses due to corona discharge recorded at selected monitoring points along a 220 kV overhead transmission line. Here, the monitoring-section number denotes the sequential index of each selected measurement point along the line [8-13].

2. Analysis of the Research Results

Corona-related losses are determined using the specific

power losses and data on the duration of different meteorological conditions during the calculation period. For calculating corona losses, fair-weather periods are defined as periods when the relative humidity is below 100% and the conductors are free of ice. If data on the duration of meteorological conditions during the calculation period are unavailable, corona losses are determined with regard to the region in which the transmission line is located. Power losses due to corona discharge vary over a wide range, following a second-order relationship; in some cases, they can change rapidly over time. To characterize corona losses, continuous data on changes in meteorological parameters and corona losses are required over a 10-12-year solar activity cycle, since the cyclic recurrence of meteorological phenomena is largely determined by this cycle. At the theoretical stage, the radial distribution of electric field strength around the conductor in a cylindrical coordinate system is expressed using Laplace's equation (Equation (4)):

$$\nabla^2 \phi = 0 \quad (4)$$

Here ϕ -electric potential.

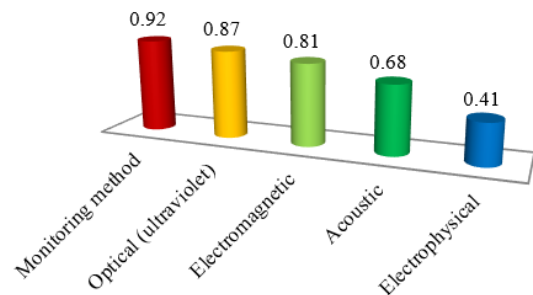


Figure 5. Comparison of Monitoring Methods for Corona-Loss Assessment.

The chart compares values from 0.41 to 0.92. However, “Monitoring method” appears as a category label for 0.92, while “Visual observation” is missing. Please check the labels and state what the values represent (including units, if applicable) before using the figure.

Share of Energy Losses Due to Corona on a 110 kV Overhead Transmission Line

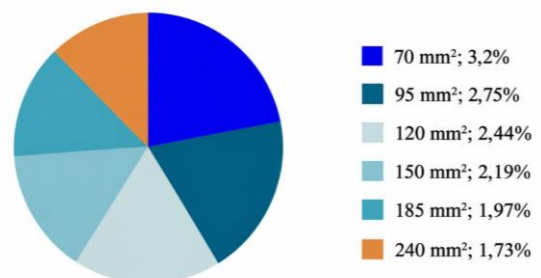


Figure 6. Comparison of corona-related energy-loss shares by conductor cross-section in a 110 kV overhead transmission line.

The figure compares the reported share of corona-related energy losses for conductor cross-sections ranging from 70 to 240 mm². The share decreases from 3.20% to 1.73%, a reduction of 1.47 percentage points, or approximately 45.9% relative to the 70 mm² case. This comparison is valid when the operating voltage and atmospheric and operating conditions are held constant.

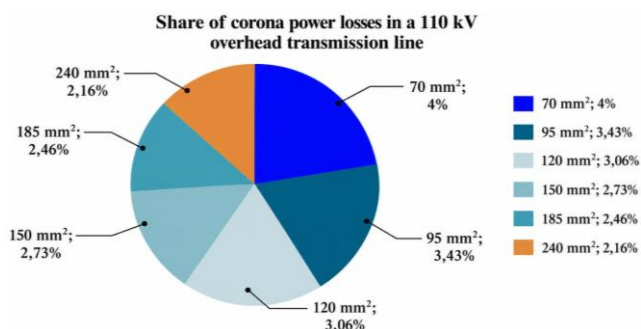


Figure 7. Comparison of corona-related energy-loss shares by conductor cross-section in a 110 kV overhead transmission line.

The chart shows a decrease in the corona-loss share as conductor cross-sectional area increases, from 4.00% at 70 mm² to 2.16% at 240 mm².

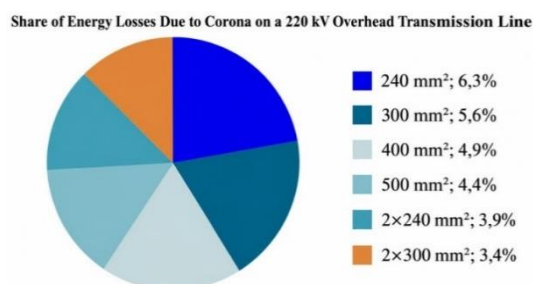


Figure 8. Share of Corona-Induced Energy Losses by Conductor Configuration on a 220 kV Overhead Transmission Line.

The chart compares six conductor configurations. The reported corona-loss share decreases from 6.3% for 240 mm² to 3.4% for 2 × 300 mm².

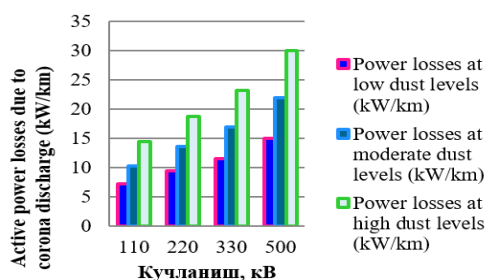


Figure 9. Active Power Losses Due to Corona Discharge at Different Voltage and Dust Levels.

The plotted values show that active power losses increase with voltage and dust level, reaching 30 kW/km at 500 kV under high-dust conditions.

3. Conclusions

The results indicate that corona losses in overhead transmission lines depend jointly on operating voltage, atmospheric dust, and conductor configuration. At 500 kV, the plotted active power losses are approximately 15 kW/km under low-dust conditions, 22 kW/km under moderate-dust conditions, and 30 kW/km under high-dust conditions. Thus, the high-dust value is twice the low-dust value. The 110 kV graph likewise shows an increase from approximately 7 kW/km at low dust to 14.5 kW/km at high dust. The reported observations also associate higher humidity and fog with increased corona activity, including at particular sections along the line. The conductor comparisons show a consistent reduction of about 46% in the reported corona-loss share as conductor cross-section or configuration increases. For the 110 kV cases, the figures report decreases from 3.20% to 1.73% and from 4.00% to 2.16%.

For the 220 kV line, the share decreases from 6.3% for a 240 mm² conductor to 3.4% for a 2 × 300 mm² configuration. These results support assessing conductor design alongside voltage and weather conditions. Continuous monitoring that combines electrical, electromagnetic, meteorological, and location-specific measurements can help identify high-loss sections and improve operational loss estimates. Power-loss rates in kW/km should be kept distinct from energy-loss shares in percent. The two 110 kV comparisons give different absolute percentages; clarify whether they represent different operating cases. The monitoring-method chart also needs its category labels and the meaning and units of its 0.41–0.92 values specified.

Abbreviations

ΔP_{cor} The Power Loss

Author Contributions

Tovbayev Akram Nurmonovich: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Methodology, Resources, Software, Validation, Writing – original draft, Writing – review & editing

Tog'ayev Islom Bekpo'lat o'g'li: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Validation, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography



Tovbayev Akram Nurmonovich is a Doctor of Technical Sciences (DSc) and Professor at Navoi State University of Mining and Technology, Navoi, Uzbekistan. His research interests include electrical power engineering, power supply systems, high-voltage overhead transmission lines, power quality, ferroresonance phenomena, subharmonic oscillations, corona discharge, electrical energy losses, monitoring and diagnostics of power transmission systems, and energy efficiency. His recent research focuses particularly on the analysis and reduction of corona-induced power losses in high-voltage overhead transmission lines and the development of monitoring approaches for improving the reliability and energy efficiency of electrical power systems.



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Research Field

Tovbayev Akram Nurmonovich Electrical Power Engineering; High-Voltage Power Systems; Power Quality; Power Transmission Lines; Energy Efficiency; Electrical System Monitoring and Diagnostics.

Tog'ayev Islom Bekpo'lat o'g'li: Electrical Power Engineering, Power Supply Systems, High-Voltage Transmission Lines, Power Quality, Energy Efficiency, Power Grid Monitoring and Diagnostics.