Integrated methods for assessing and mitigating corona-induced active power losses in 110–220 kV overhead transmission lines operating under desert climate conditions

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Abstract. The article corona losses are evaluated based on the power dissipated per unit length of the transmission line and on the duration of various weather conditions within the assessment period. For the purpose of corona-loss calculations, fair-weather conditions are defined as periods with relative humidity below 100% and without ice accretion on the conductors. In contrast, wet-weather conditions correspond to rainfall, wet snow, or fog. When long-term weather-duration statistics for the calculation interval are unavailable, corona losses are estimated according to the climatic characteristics of the region in which the transmission line is located. Corona power losses exhibit an extremely wide range of variability typically spanning two orders of magnitude and their fluctuations over time can be very rapid. As a result, periodic measurements conducted on test sections of the line do not provide sufficiently reliable values of average or maximum corona losses. To fully characterize corona-loss behavior, continuous long-term data on meteorological parameters and corona discharge energy over an entire solar activity cycle (approximately 10–12 years) are required, since the recurrence of many atmospheric phenomena follows this solar-cycle periodicity.

INTRODUCTION

Corona losses refer to the energy dissipated during electric power transmission as a consequence of corona discharge formation along the conductors. A corona discharge represents a specific type of self-sustained gaseous discharge that develops in regions of highly non-uniform electric fields. A distinctive feature of corona is that ionization processes generated by free electrons do not extend along the entire medium but occur primarily in the vicinity of the electrode-for instance, around an overhead line conductor. This region is characterized by electric field intensities significantly higher than the average field values in the surrounding space. When the local electric field approaches its critical strength, a luminous envelope-commonly observed as bluish glow-forms around the electrode, giving rise to the phenomenon known as corona. The energy losses arising during corona discharge result from collisions between ions and air molecules within the electric field surrounding the conductor, which in turn causes localized heating of the air. To analyze the characteristics of corona discharge experimentally, measurements were conducted on specially designed test spans equipped with conductors whose cross-sectional parameters, configurations, and spatial arrangements closely replicate those found in practical transmission systems. Along the length of an overhead transmission line, the electric field and voltage distribution are not perfectly uniform. In addition, minor surface irregularities or roughness on the conductor may be present. These factors because the electric field intensity to increase locally at certain points on the conductor surface, leading to the early initiation of corona discharge not over the entire conductor, but only within limited, highly stressed regions. This phenomenon is referred to as local corona or partial corona discharge. When corona discharge develops uniformly along the entire conductor surface and results in measurable energy dissipation over the full conductor length, the phenomenon is classified as general corona. Considering that, within the Russian climatic zone, approximately 6000 hours out of the average 8760 hours per year fall under fair-weather conditions, the diameters of conductors used in overhead transmission lines are selected such that general corona does not occur under typical fair-weather operating conditions [1-5].

TABLE 1. The calculated average annual corona power dissipation

Voltage U_n, kV	Number of conductors per phase	Cross-section of AC conductor	Conductor radius, mm	Losses, W/m		Ratio P_2/P_1
				P_1	P_2	
750	5	240/56	11.2	13	25	1.9
500	3	330/43	15.3	9	11.6	1.3
330	2	300/39	13.7	3.8	4	1.05
220	1	300/39	12	1.6	2.9	1.25
110	1	240/16	10	1	2	1

For 500-kV and 220-kV overhead transmission lines, the durations of increased corona power losses were recorded as approximately 3.3 hours and 2.5 hours, respectively. Figure 1 presents the corresponding histograms of corona losses, based on which the specific (normalized) values of electrical energy losses due to corona discharge were determined [6-8].

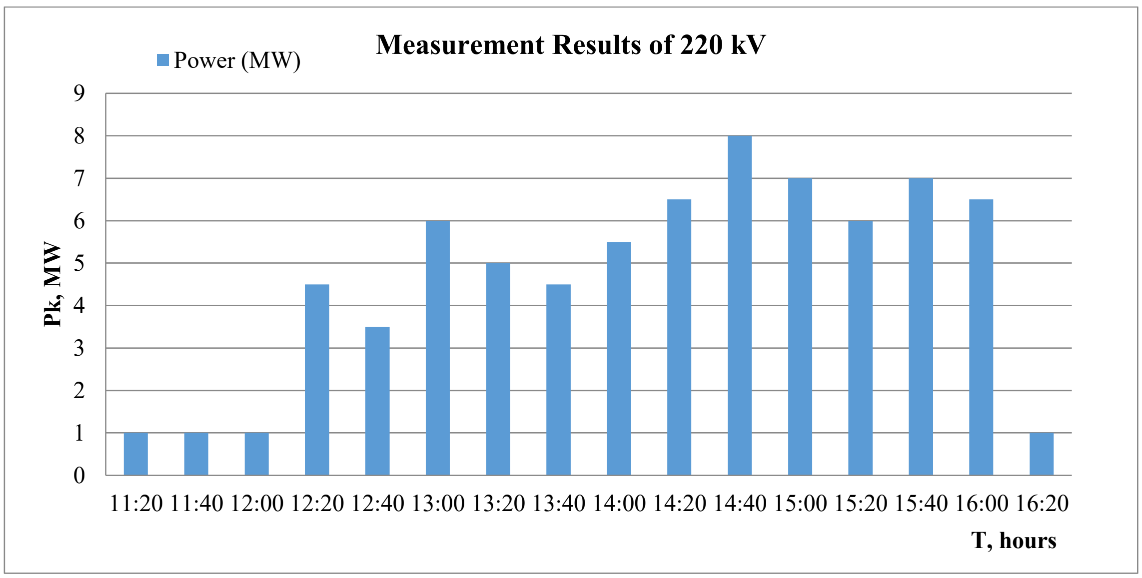

FIGURE 1. Histogram of corona power losses for 500 kV and 220 kV overhead transmission lines

EXPERIMENTAL RESEARCH

In order to overcome the lack of sensitivity in measuring corona losses under conditions where the relative humidity of air exceeds 90%, it is necessary to install meteorological stations at all substations operating at 330 kV and above. At the present stage, however, this shortcoming in the system can be partially compensated by applying correction factors to corona-loss measurements obtained under fair-weather conditions. These factors take into account the ratio between the average annual duration of periods with high humidity and that of fair-weather periods. Such an approach makes it possible to determine, in real time, the individual components of total energy losses-namely, load losses, corona losses, and leakage losses along insulation. This, in turn, enables optimization of power-system operating modes, reduction of overall losses in the network, and a significant improvement in the efficiency of electric energy use [9-12]. The temperature of an overhead line conductor is influenced by multiple factors, primarily the magnitude of the current flowing through it, the ambient air temperature, wind speed, and the level of solar radiation. According to monitoring results of the transmission network, the average annual loading of the lines does not exceed 30% of their thermal capacity. Under loading conditions of 30% or less, the influence of current magnitude and wind speed on conductor temperature-and consequently on its electrical resistance-is sufficiently small that it may be reasonably neglected without introducing significant error into calculations.

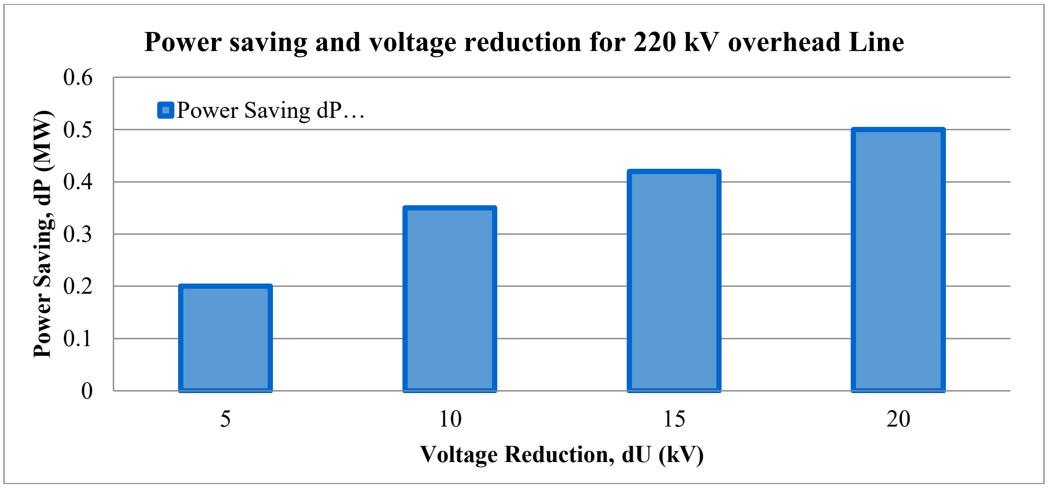

FIGURE 2. Corona power loss supply frequency for different excitation modes.

RESEARCH RESULTS

The instrumental error associated with determining conductor losses is relatively small: at a maximum absolute deviation of 1151 kW, it amounts to approximately 4% of the measured conductor-loss value. When compared to the natural transmission capacity of the overhead line (855,000 kW), this error corresponds to only about 0.13%, indicating that its influence on the overall assessment of power losses is negligible.

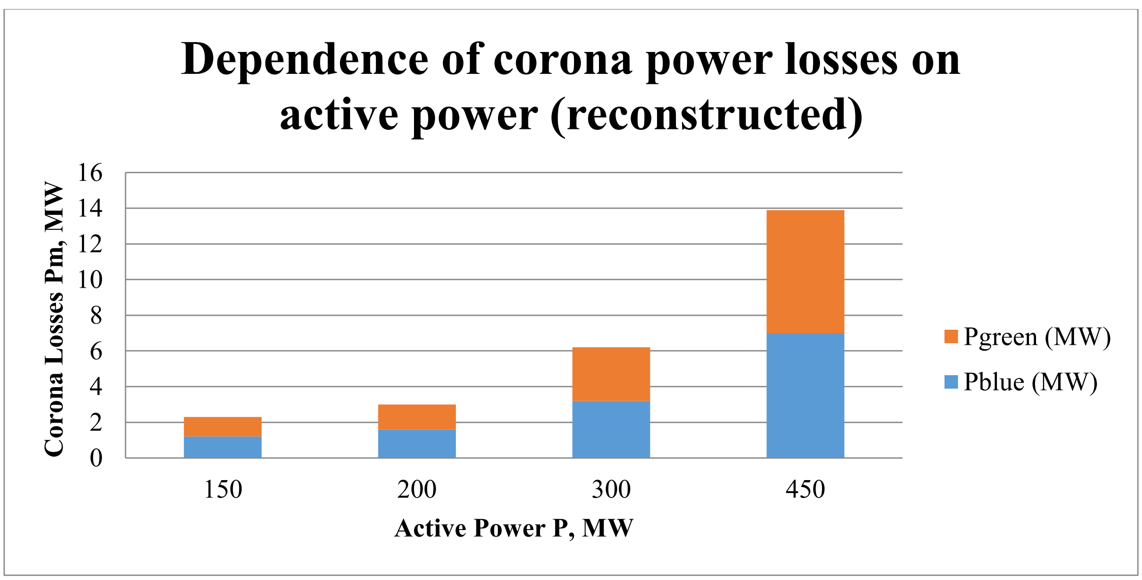

FIGURE 3. Relationship between corona losses and active power in high-voltage transmission lines.

For the transmission line under consideration, the corona losses in fair-weather conditions amount to 1200 kW. As shown in Figure 3, the maximum absolute instrumental error in determining corona losses reaches 229 kW, which corresponds to about 19% of the corona power loss measured under fair-weather conditions. In such conditions, corona losses are calculated based on the measured voltage and the computed capacitive charging current. Given that the uncertainties associated with determining these parameters are relatively large, and also considering that fair-weather corona losses are approximately two orders of magnitude smaller than the maximum possible corona-loss values, it can be concluded that an error margin of 19% in the computation of corona losses is fully acceptable for engineering assessments [13-15].

TABLE 2. Key performance indicators of corona losses and power flow parameters.

Parameteres	Value
Duration of increased corona losses, hours	2,33
Average voltage at the end of U_2, kV	507,13
Average active power flow at the end of P_2, MW	60
Average reactive power flow at the end of Q_2, MVAR	195
Average corona losses, MW	10,61
Average loan losses P_{n2}, MW	1,24
Total line losses P_{tot}, MW	13,5
Optimal voltage at the end of the line U_{2opt}, kV	327,27
Total losses at optimal voltage P_{totopt}, MW	4,16
Potential reduction effect of total losses, MW	7,69

In the previous section, the operating mode of an individual transmission line was considered. However, when analyzing the power system as a whole, it is necessary to account for the losses occurring across all lines within the specified region [29-58]. Therefore, when determining the optimal voltage levels at system nodes, both corona losses and load losses for all transmission lines in the examined energy area must be included in the calculations.

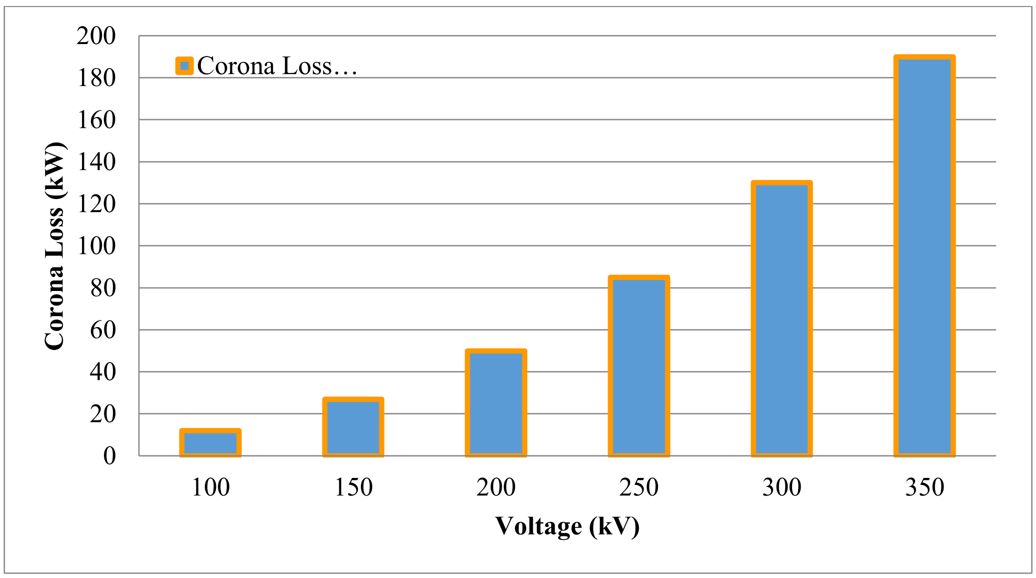

FIGURE 4. Corona loss and voltage

Analysis of the measurement results demonstrates that it is possible to distinguish and evaluate, in real time, all major components of power losses in overhead transmission lines-namely, load-related active power losses, corona discharge losses, and leakage losses along insulation. This capability provides a solid basis for optimizing the operating modes of transmission lines, reducing total losses, and significantly increasing the overall energy efficiency of industrial and power-system processes [16-28]. The findings further indicate that, in power-system voltage optimization studies, neglecting corona-related losses leads to inaccurate assessments and suboptimal decision-making. Therefore, corona power losses must be treated as one of the essential parameters when determining the optimal voltage levels across the energy system. Preliminary analytical and computational investigations reveal that corona losses play a crucial role when optimizing the operating mode of a single overhead line through voltage regulation.

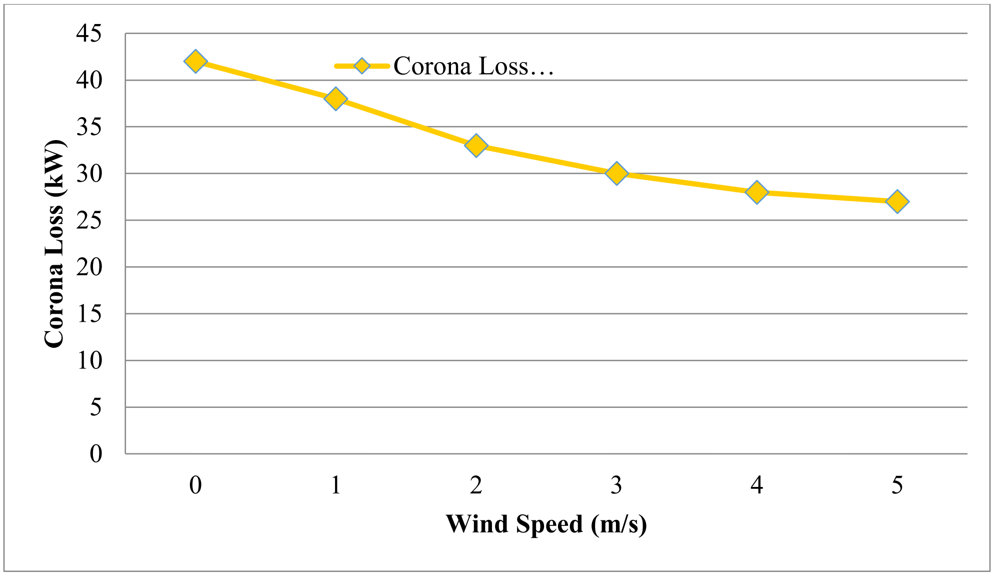

FIGURE 5. Wind speed effects on corona

Under adverse weather conditions (humid, polluted, snow-covered), corona losses increase sharply. Consequently, the optimal voltage becomes significantly lower than the nominal voltage, usually within a range of 0.5-0.85. This behavior is primarily explained by the reduction of the critical electric field strength due to high humidity and surface contamination, which greatly intensifies corona discharge activity and associated energy losses.

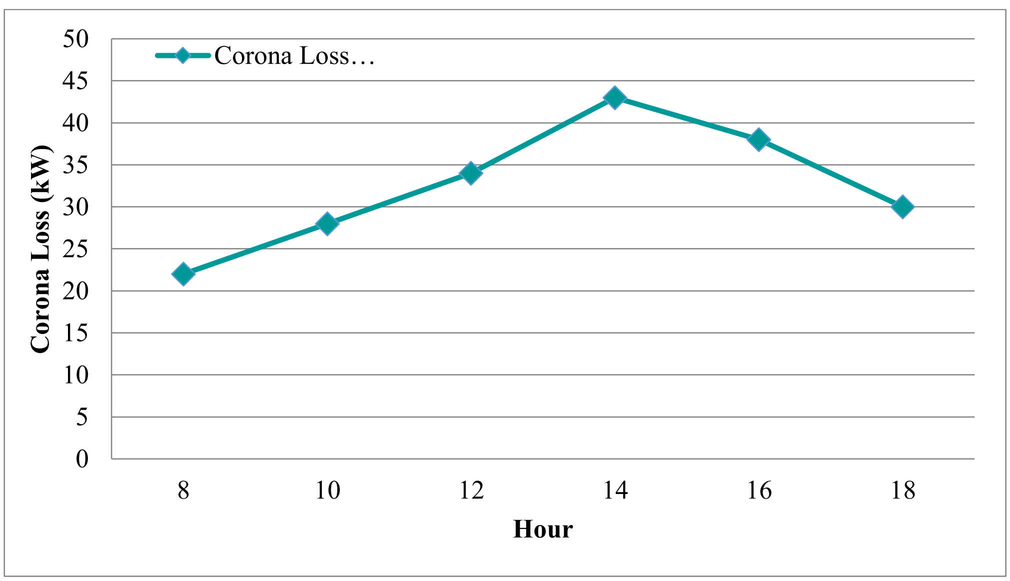

FIGURE 6. Corona loss over daily cycle

Additionally, it should be emphasized that, in both operating scenarios, accurate determination of the optimal voltage requires dynamic consideration of corona-related parameters along with load losses. For extra-high voltage transmission lines, the contribution of corona losses may reach 20–40% of the total losses, making it technically unacceptable to disregard them in optimization and operational studies.

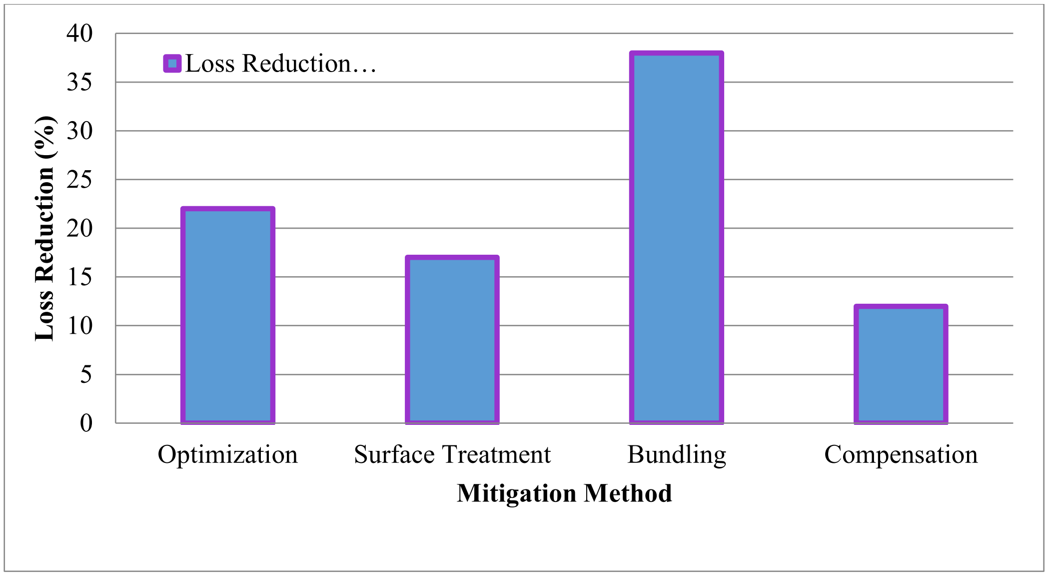

FIGURE 7. Efficiency of mitigation techniques

Analysis of the computational errors associated with determining corona losses using the algorithms of the long-distance integrated calculation software package demonstrated that applying more accurate formulas-specifically those that account for the wave properties of overhead transmission lines-provides a significantly improved estimation of load losses in long conductors.

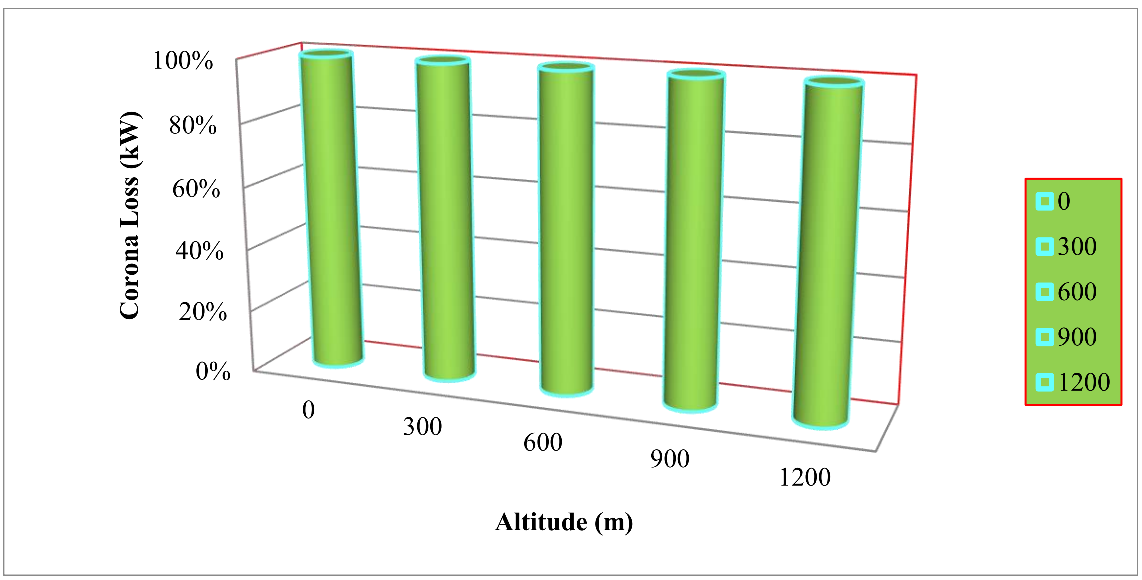

FIGURE 8. Altitude and corona loss

Under fair-weather conditions, for transmission lines exceeding 250 km in length, the influence of voltage variations along the line on corona power losses becomes substantial. To properly account for this effect, a correction factor dependent on both active and reactive power was introduced into the algorithm of the Long-Distance Integrated Calculation Program. Within this software environment, corona-loss data obtained from real operational measurements were analyzed. These results were compared with two existing long-distance high-voltage transmission lines and correlated with meteorological observations from weather stations located near the line routes. This comparative assessment confirmed that increased corona losses are strongly associated with adverse meteorological conditions.

CONCLUSIONS

The conducted analysis demonstrates that real-time measurements make it possible to isolate and quantify all principal components of power losses in high-voltage overhead transmission lines—namely, load-related active power losses, corona discharge losses, and insulation leakage losses. The ability to decompose these loss components provides a strong analytical foundation for optimizing transmission-line operating modes, reducing total losses, and significantly improving the overall energy efficiency of the power system. The study confirms that corona-related losses must be explicitly included when determining optimal voltage levels across the network. Neglecting corona effects leads to substantial inaccuracies in loss evaluation and may result in suboptimal voltage-control decisions. In contrast, incorporating corona-loss behavior into voltage-optimization algorithms allows a more realistic representation of line performance under varying atmospheric and loading conditions. Computational investigations further reveal that the influence of corona losses becomes particularly important for long-distance transmission lines. Under favorable weather conditions, the optimal operating voltage tends to exceed the nominal value by approximately 20–25%, primarily due to the relatively low magnitude of corona losses. During adverse weather—characterized by elevated humidity, surface contamination, or snow—the opposite tendency is observed: corona losses increase sharply, and the optimal voltage decreases to nearly 50–85% of the nominal level. This behavior is directly linked to the reduction of the critical electric-field strength that triggers intensified corona discharge activity. For transmission lines exceeding 250 km, voltage variation along the line has a measurable impact on corona losses. To account for this effect, the long-distance integrated calculation algorithm was supplemented with a correction factor dependent on both active and reactive power flows. This enhancement enables more accurate modeling of corona phenomena and improves agreement between computational and field-measured results. A comparative assessment of experimental data from two operating high-voltage lines, combined with observations from nearby meteorological stations, shows a clear correlation between increased corona losses and deteriorating weather conditions. This finding highlights the necessity of continuous monitoring and adaptive control strategies, particularly for extra-high-voltage and long transmission corridors. Overall, the results validate the practical effectiveness of the proposed analytical methods and optimization procedures. Considering corona losses as an integral part of transmission-line performance modeling enhances operational reliability, reduces energy losses, and contributes to more efficient and sustainable functioning of the power system.

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