Improvement of the operational energy efficiency of high-voltage overhead transmission lines through the mitigation of corona-induced power losses

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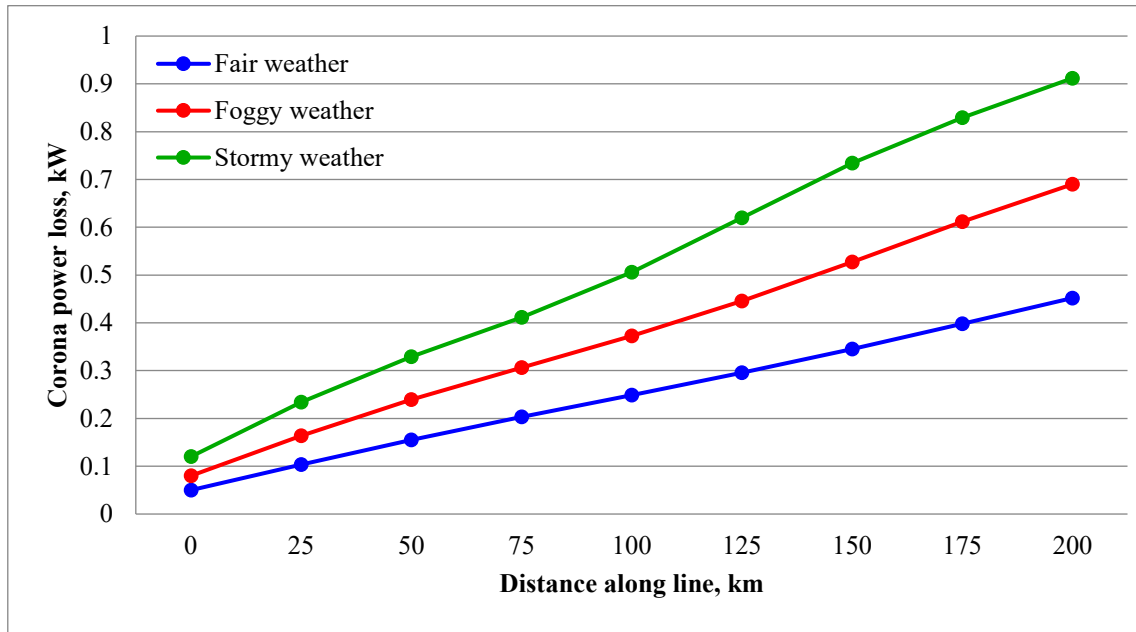*[2] Samarkand State of architecture and Construction University, Samarkand, Uzbekistan*

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Abstract. This article presents the specific features and analytical stages of an algorithm developed for calculating corona losses in overhead transmission lines. The procedure is based on detailed modeling of the line, where each active conductor is treated as an independent element and the corona-induced power dissipation is evaluated separately for every conductor. Such a modelling approach makes it possible to determine the optimal configuration and spacing of conductor bundles, thereby ensuring both the reduction and the uniform redistribution of corona losses. The number of subconductors in a phase, as well as their geometrical arrangement, has a pronounced influence on the magnitude and asymmetry of corona-related losses. Therefore, corona effects are incorporated and assessed during the design stage of overhead transmission lines. This includes optimizing the operating conditions of power supply systems with respect to voltage levels, reactive power management, and power flow control parameters. Furthermore, the study highlights the need for developing a dedicated measurement and assessment methodology that enables accurate evaluation of the operating state of high-voltage transmission lines under real conditions and quantifies power and energy losses caused by corona phenomena. In addition, the dependence of load and corona losses on system voltage levels is analyzed. The work evaluates the balance between load losses and corona-induced losses in high-voltage overhead lines, emphasizing its importance in selecting the optimal transmission voltage level and establishing an overall loss-minimization strategy for electrical power systems.
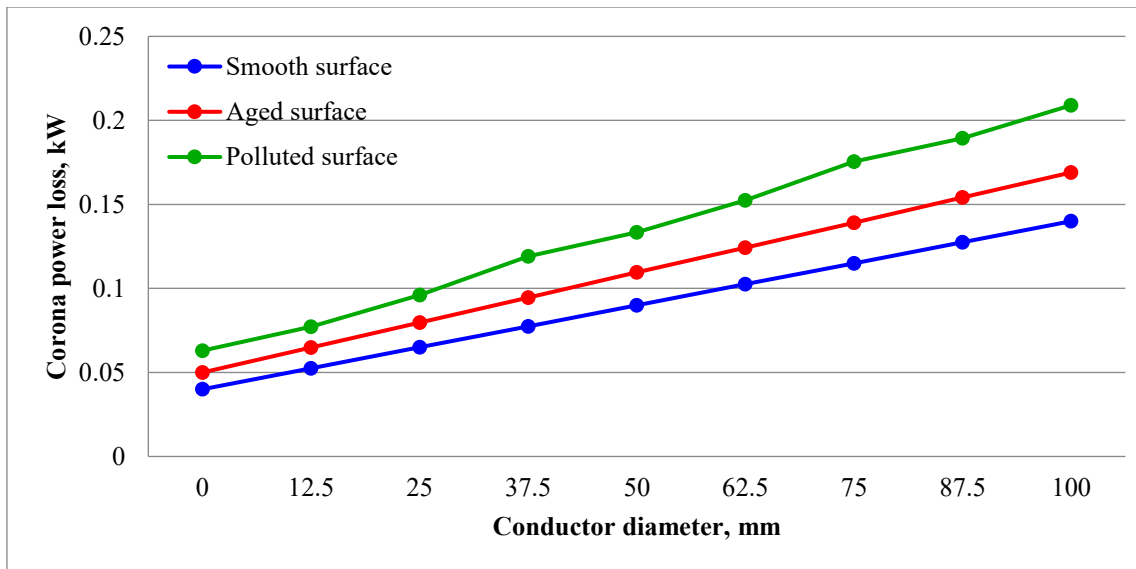
INTRODUCTION

The evaluation of instantaneous, daily average, and annual average energy losses in high-voltage overhead transmission lines, as well as the integration of corona power-loss calculation results into analytical and optimization platforms designed for assessing the stable operating modes of power systems requires the development of a dedicated technological framework. This framework must also incorporate an in-depth investigation of the errors associated with existing methods used to determine corona-and conductor-related current losses, followed by improvements aimed at increasing their precision. At present, several analytical approaches and diagnostic techniques are available, however, the assessment of small-magnitude corona energy losses especially under high-humidity atmospheric conditions and the sensitivity of real-time measurement methods applied to conductor losses remain among the critical research challenges for high-voltage overhead transmission lines. These methodological aspects play a significant role in ensuring the reliability and efficiency of modern power transmission systems [1]. The relocation of any material object from one point to another inevitably requires a certain amount of expenditure. In contrast, electrical energy is the only product that consumes itself during transmission through power networks, without the need for additional external resources. The actual losses of electrical energy are defined as the difference between the energy supplied to the electrical grid and the energy delivered to end-users in a useful form. These losses encompass the physical transmission losses that occur within network elements, the energy consumed by equipment installed at substations to ensure the transmission process, as well as commercial (non-technical) losses. The power transmission system is designed in such a way that, under fair-weather conditions, the losses in high-voltage transmission lines operating at 110 kV and above are reduced to approximately 0.65 kW per kilometer.

FIGURE 1. Corona power loss vs line length under different weather conditions.

Examples of corona-related losses are typically reported for operating conditions such as fog, dew, precipitation, ice accretion, snow, and sand-carrying winds. Most of these studies assume that the transmission line is configured in an ideally symmetrical arrangement. Consequently, the influence of phase asymmetry on corona power losses remains insufficiently addressed, which makes it necessary to investigate how deviations from geometrical or electrical symmetry affect the magnitude and distribution of corona-induced losses [2-5].
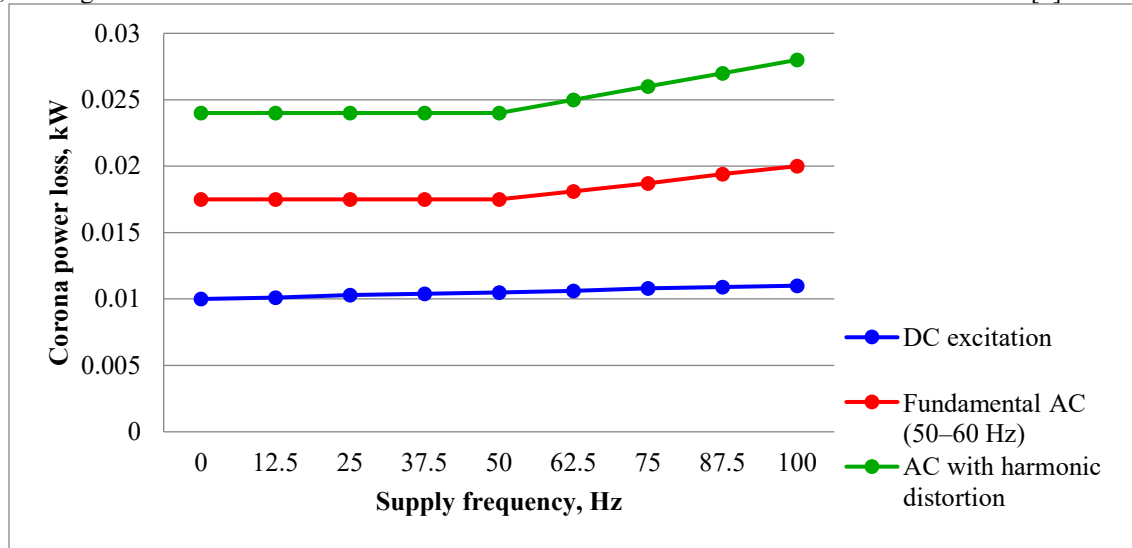

FIGURE 2. Corona power loss and conductor diameter for different surface conditions.

EXPERIMENTAL RESEARCH

Another capability of the algorithm is the possibility of specifying the number of hours during which moisture or dust accumulation is assumed to occur on the lower surface of the conductors throughout the year. This condition
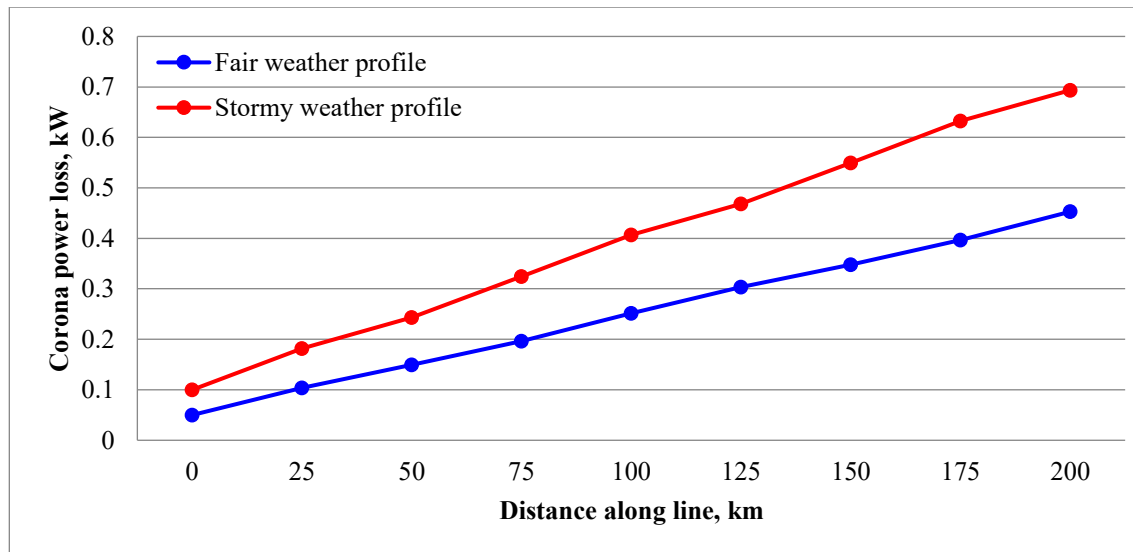
typically arises during periods of low power demand, when the conductors operate at reduced temperatures. During temperature-induced condensation, the disruptive voltage level along the entire line may decrease by approximately 20%, causing corona losses to increase in a manner similar to that observed under rainfall conditions [6].

FIGURE 3. Corona power loss supply frequency for different excitation modes.

RESEARCH RESULTS

After all input parameters are entered, the program computes the maximum operating voltage of the line, which in this example equals 205.63 kV (phase-to-phase). The critical or disruptive corona onset voltage is calculated to be 45.37% higher than the maximum operating voltage.

FIGURE 4. Longitudinal profile of corona power loss along the transmission line.
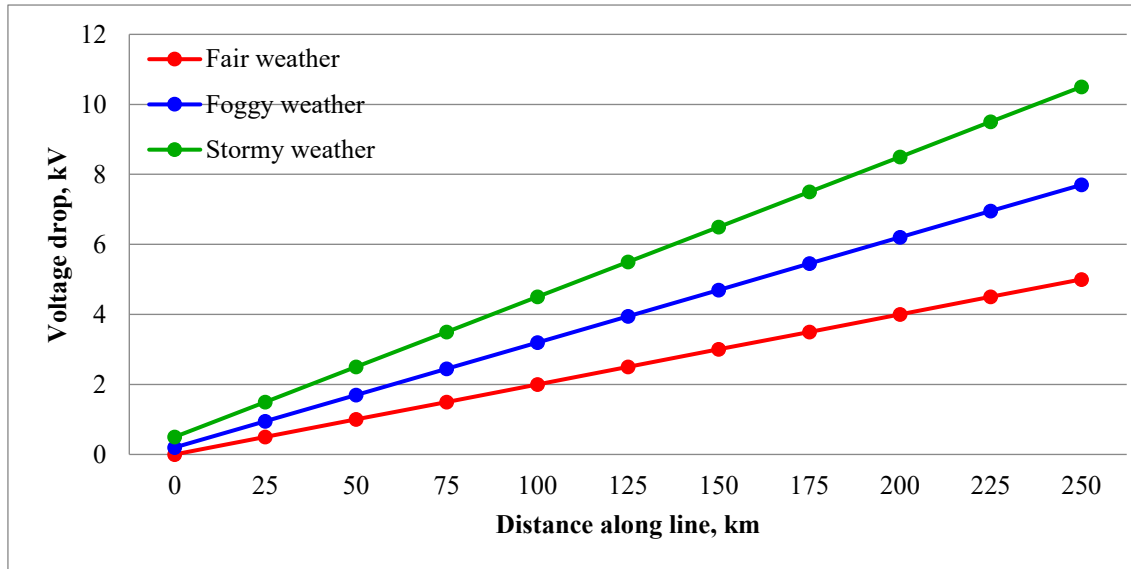
The occurrence and intensity of corona discharges, as well as the associated power losses, are influenced by a range of factors. These include the electric field gradient at the conductor surface, the technical and physical condition of the conductor surface, prevailing weather conditions, the relative air density, the presence of moisture or water films on the conductor, the average operating voltage of the line, and the diameter and geometric dimensions of the phase conductors. In addition, the configuration of bundled conductors, the presence or absence of shielding (ground) wires, non-uniformities in the phase and shielding conductors, and deviations from geometrical

symmetry also exert a direct influence on the initiation and intensity of corona discharges and the losses they produce.

TABLE 1. Data on the phase conductors and the shielding (ground) wires of the transmission line under study.
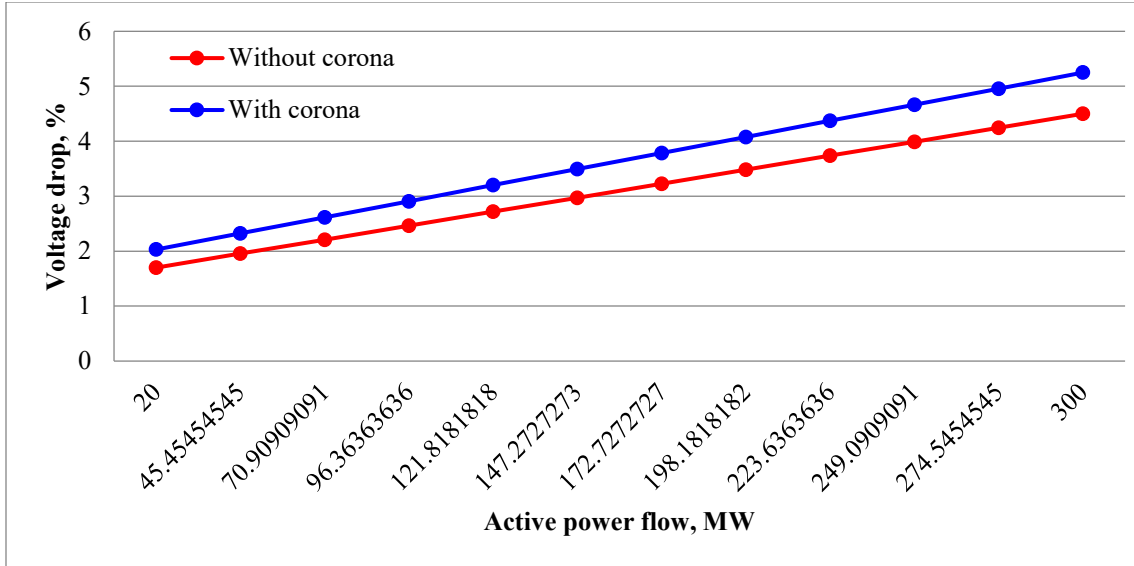
Conductor	Internal resistance, Ω/km	"Diameter, mm	Average geometric radius, mm
Phase	0.08	27.5	11.110
Ground wire	2.00	11.0	0.00015

   To accurately characterize the behavior of corona losses, it is essential to have long-term data-spanning an entire solar activity cycle of approximately 10-12 years on the continuous variation of weather parameters and corona loss levels. This requirement is due to the fact that the cyclic recurrence of meteorological phenomena is closely governed by the periodic nature of solar activity.
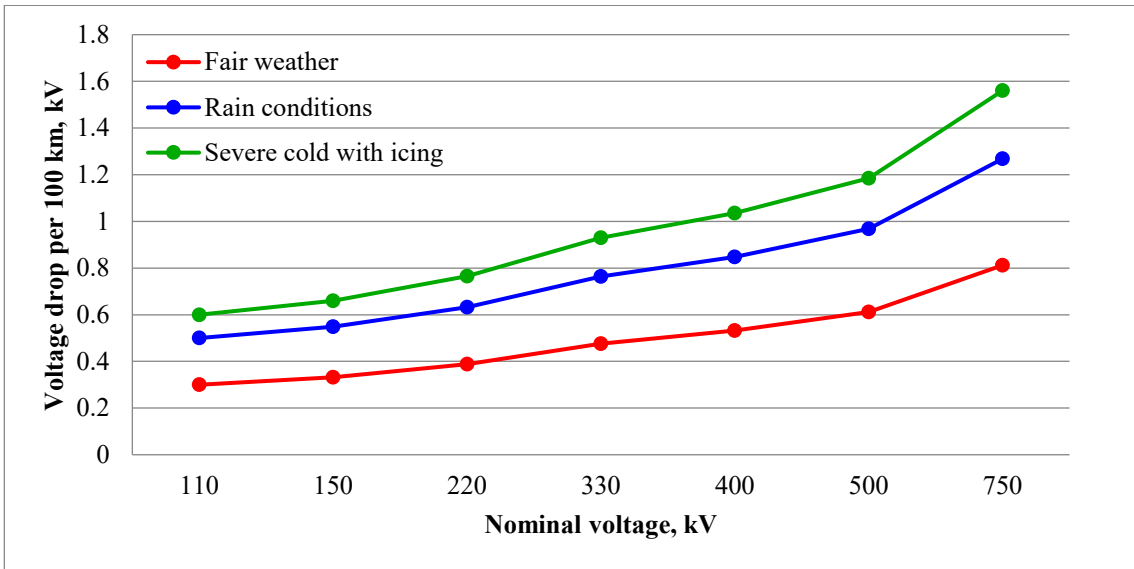

FIGURE 5. Corona power loss supply frequency for different excitation modes. Voltage drop along a 220 kV overhead line due to corona (different weather conditions)

   Corona losses represent the portion of energy dissipated during electric power transmission as a result of the formation of corona discharges, which themselves are a characteristic form of independent gaseous ionization occurring in regions of highly non-uniform electric fields. In alternating-current transmission systems, the viscous-ionization mechanism contributes to maintaining system reliability and plays a role in reducing losses under normal operating conditions. However, under adverse meteorological conditions-particularly rainfall, wet snow, fog, and icing-the corona onset voltage decreases significantly, leading to an increase in the overall corona activity and, consequently, higher energy losses. For transmission systems operating at nominal voltages of 500 kV and above, it become advantageous to employ conductors with a relatively large outer diameter but a smaller cross-sectional area, as such conductors help to mitigate corona-related power dissipation by reducing the electric field intensity at the conductor surface. In practical design applications, the average corona power losses in high-voltage overhead transmission lines are typically evaluated based on long-term operational observations. In most cases, the assessment of active power losses caused by corona under a given network operating mode relies on annual average values, which are adopted according to the recommendations of various technical guidelines. However, these averaged estimates do not account for the specific meteorological conditions, structural characteristics, or actual operating parameters of the overhead line in question. The reported annual durations of characteristic weather conditions are generally derived from the aggregated results of weather monitoring performed by meteorological stations, which provide generalized climatological statistics rather than line-specific data [7-20].
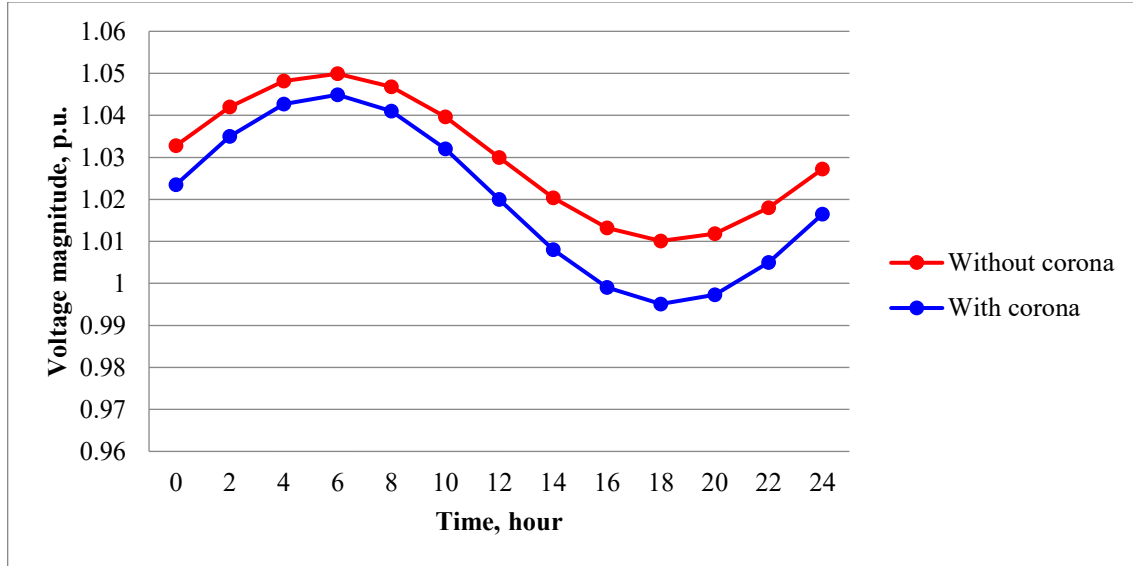
FIGURE 6. Relative voltage drop and active power flow (including corona component)

FIGURE 7. Specific voltage drop due to corona and nominal voltage level

The analysis of errors in determining corona losses using long-distance integrated computational algorithms has demonstrated that, for long overhead transmission lines, it is advisable to employ more accurate formulations that incorporate the wave-propagation characteristics of air-insulated lines when calculating load losses in the conductors. This approach provides a more precise representation of the physical processes governing energy dissipation along extended transmission corridors.

FIGURE 8. Daily variation of bus voltage magnitude with and without corona

FIGURE 9. Maximum end-of-line voltage drop and line length for different bundle configurations

The measurement results demonstrate that it is possible to determine, in real time, the individual components of total energy losses-namely load losses, corona-related losses, and power dissipation-within the transmission system. This capability enables the optimization of operating modes of high-voltage overhead lines with the objective of reducing losses and achieving significant energy savings. Furthermore, it has been shown that operational optimization based on system voltage levels cannot be carried out accurately without incorporating the real-time corona power losses into the analysis. High-voltage overhead transmission lines constitute one of the most critical elements of modern power systems, and their operational efficiency directly determines the stability, reliability, and economic performance of the entire energy network. One of the fundamental limiting factors in their performance is the occurrence of corona discharge, which becomes increasingly pronounced as transmission voltages rise and as the surrounding meteorological environment deviates from standard conditions.

TABLE 2. Active power losses caused by corona discharge in overhead transmission lines based on the average parameters of phase configuration

Nominal voltage (kV)	Specific corona power loss in an overhead transmission line under various weather conditions, kW/km			
	Fair-weather conditions	Dry-snow conditions	Rain conditions	Severe cold conditions
750	4.20	16.55	60	122.5
500	2.30	8.80	29	76
330	0.90	3.90	13	28.8
220	0.30	1.10	3	12
110	0.03	0.12	0.35	1.2

CONCLUSIONS

The research performed within this study demonstrates that corona-induced power losses, although sometimes underestimated in traditional design practice, represent a dynamically varying component of total transmission losses and must therefore be integrated into the operational and planning models of power systems. The analytical investigation shows that corona discharge depends strongly on the electric field distribution along the conductor surface, which itself is a function of conductor geometry, surface roughness, bundle configuration, atmospheric conditions, and the instantaneous operating voltage. The results confirm that corona losses do not remain constant but fluctuate significantly during rain, fog, high humidity, wet-snow, and icing and during periods of condensation on cold conductors. This variability requires a shift from the conventional use of long-term averaged values to a more adaptive approach capable of responding to real-time environmental conditions. Incorporating such adaptive methods yields more accurate loss calculation and creates a basis for voltage-level optimization across the transmission corridor. The study further establishes that improving energy efficiency cannot be achieved merely through conventional load-flow control or reactive power compensation. Instead, meaningful improvement is attainable only when corona-related losses are explicitly integrated into optimization algorithms. Real-time measurement systems and long-distance computational models demonstrate that corona losses can alter the effective voltage distribution along extended lines and significantly influence optimal system voltage selection. In particular, lines operate at 500 kV and above exhibit high sensitivity to corona effects, necessitating the use of conductor types with larger diameters, optimized bundle configurations, and improved surface characteristics to reduce electric field gradients. Integrating corona loss data into operational control systems provides tangible benefits. The ability to decompose total losses into load losses, corona losses, and additional dissipative components in real time enables more accurate system-wide optimization. This enhances the effectiveness of voltage regulation strategies, reactive power balancing, conductor selection, and system-wide loss minimization initiatives. The study conclusively shows that operational optimization-whether by voltage level, by load distribution, or by compensation schemes-cannot be considered technically complete unless real-time corona loss estimation is included. Overall, the findings of this research demonstrate that mitigating corona-induced losses is not merely an incremental improvement but a strategically essential measure for future high-voltage networks. Implementing advanced conductor designs, adopting multi-criteria operational control, and incorporating corona-aware optimization algorithms result in a measurable reduction of energy losses, improved voltage stability, and enhanced overall efficiency of the transmission system. These outcomes substantiate the necessity of transitioning towards corona-responsive engineering practices, which form a vital component of modern energy-efficient transmission infrastructure.

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