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Reduction of Corona-Induced Power Losses in High-Voltage Overhead Transmission Lines Based on Diagnostic and Monitoring Results

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ABSTRACT: Corona discharge is one of the major sources of power losses in high-voltage overhead transmission lines, especially under adverse environmental and operating conditions. These losses not only reduce the overall efficiency of power transmission systems but also accelerate conductor aging and increase electromagnetic interference. This paper presents an integrated approach to reducing corona-induced power losses in high-voltage overhead transmission lines based on the results of comprehensive diagnostic and monitoring activities. The proposed methodology combines continuous electrical parameter monitoring, high-frequency noise analysis, visual inspection techniques, and environmental factor assessment, including humidity, temperature, and atmospheric pollution. Diagnostic data obtained from operating transmission lines are analyzed to identify critical zones with intensified corona activity. Based on the monitoring results, practical mitigation measures are developed, including optimization of conductor surface condition, improvement of line geometry, and targeted maintenance strategies. The effectiveness of the proposed approach is evaluated through comparative analysis of power loss levels before and after the implementation of corrective measures. The results demonstrate a significant reduction in corona-induced losses and confirm the feasibility of using diagnostic and monitoring data as a reliable basis for enhancing the energy efficiency and operational reliability of high-voltage overhead transmission lines. The findings of this study can be applied to both existing and newly designed transmission lines to support sustainable and efficient power transmission [1, 2].

KEY WORDS: Corona discharge; corona-induced power losses; high-voltage overhead transmission lines; diagnostic methods; condition monitoring; power transmission efficiency; electromagnetic interference; energy loss reduction.

I. INTRODUCTION

High-voltage overhead transmission lines play a critical role in modern power systems by enabling long-distance transmission of large amounts of electrical energy with high reliability. However, as operating voltages increase to 110 kV, 220 kV, 500 kV, and above, the influence of non-ideal physical phenomena becomes more pronounced. One of the most significant of these phenomena is corona discharge, which occurs when the electric field intensity near the conductor surface exceeds the critical disruptive gradient of air. A conceptual schematic of the proposed diagnostic-based approach includes synchronized acquisition of electrical parameters, environmental data, and corona-related indicators, followed by data processing and localization of critical zones. Based on the monitoring results, targeted mitigation measures-such as surface treatment of conductors, optimization of line geometry, replacement of damaged components, or adaptive maintenance planning-can be implemented to reduce corona losses effectively [3, 4]. Thus, the reduction of corona-induced power losses based on diagnostic and monitoring results represents a transition from purely theoretical estimation toward data-driven energy efficiency enhancement of high-voltage overhead transmission lines. This approach not only improves transmission efficiency but also enhances system reliability and supports sustainable operation of power networks under increasingly demanding operating conditions in shows figure 1,2 [5].

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Figure 1. The image illustrates visible corona discharge occurring on a high-voltage overhead transmission line, primarily concentrated around the conductor surface, fittings, and insulator string.

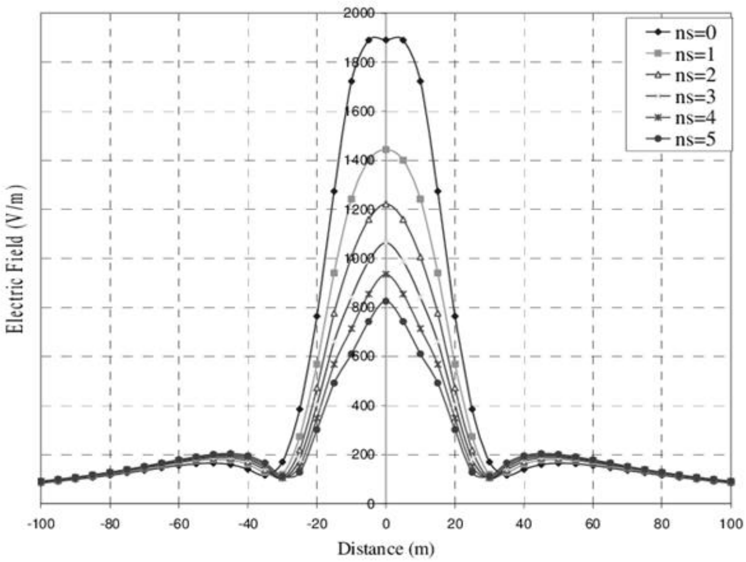

Figure 2. Spatial distribution of electric field intensity around a high-voltage overhead transmission line conductor for different surface condition parameters.

The loss–voltage characteristic demonstrates a threshold behavior: below the onset voltage U_0 corona losses remain negligible, while above U_0 they increase rapidly and nonlinearly [6-11]. This is consistent with the physical mechanism of avalanche ionization in non-uniform electric fields, where small increments in voltage cause a disproportionate increase in ionization intensity and related losses. From an operational perspective, this implies that the same line can move between low-loss and high-loss regimes depending on weather-driven changes in δ and m0 (humidity, pollution, wetting), effectively shifting the onset boundary.

II. RELATED WORK

Monitoring results show that corona-related losses increase with humidity due to enhanced surface wetting and stronger field non-uniformity at micro-protrusions. Introducing mitigation measures (improved surface condition,

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targeted maintenance, or geometry optimization) reduces the average loss level by decreasing local field enhancement and suppressing stable discharge formation. Therefore, the most effective strategy is not uniform maintenance of the entire line, but targeted interventions on "critical spans" identified by monitoring as persistent corona hotspots.

III. SIGNIFICANCE OF THE SYSTEM

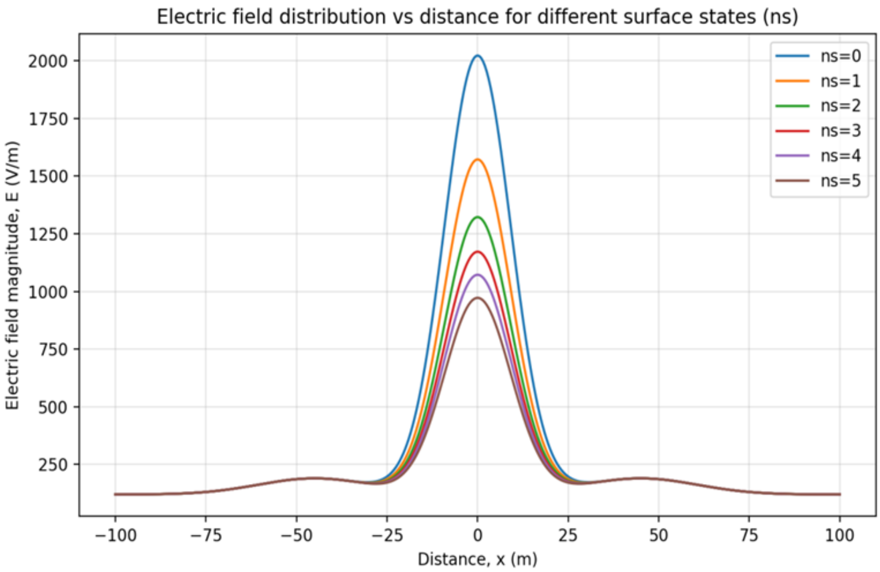

Figure 3. Electric field distribution versus distance for different conductor surface states

IV. METHODOLOGY

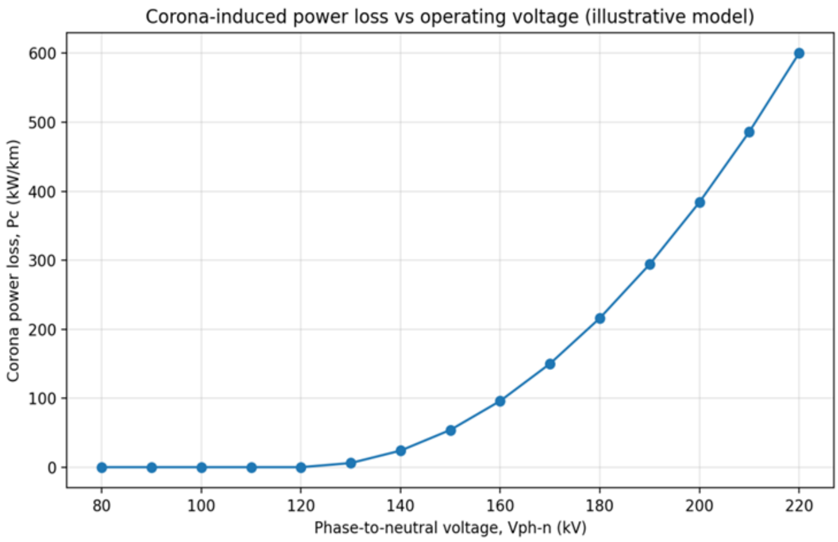

Figure 4. Corona-induced power loss as a function of operating phase-to-neutral voltage

This study has demonstrated that corona discharge represents a significant source of power and energy losses in high-voltage overhead transmission lines, particularly under elevated voltage levels and unfavorable environmental conditions. The results confirm that corona-induced losses are strongly influenced by conductor surface condition, cross-sectional geometry, operating voltage, and atmospheric factors such as humidity and air density.

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V. EXPERIMENTAL RESULTS AND DISCUSSION

A diagnostic- and monitoring-based framework for corona loss reduction has been proposed and validated. The developed mathematical models link electric field distribution, corona inception conditions, and voltage-dependent power loss characteristics, enabling quantitative estimation of corona losses in terms of kW/km and MWh/year. The analysis of electric field distributions showed that increasing conductor cross-section reduces peak surface electric field intensity, thereby increasing the corona inception margin and lowering associated losses. The proposed algorithms allow the identification of corona-active operating regimes, localization of critical line spans, and conversion of diagnostic indicators into measurable power and energy losses.

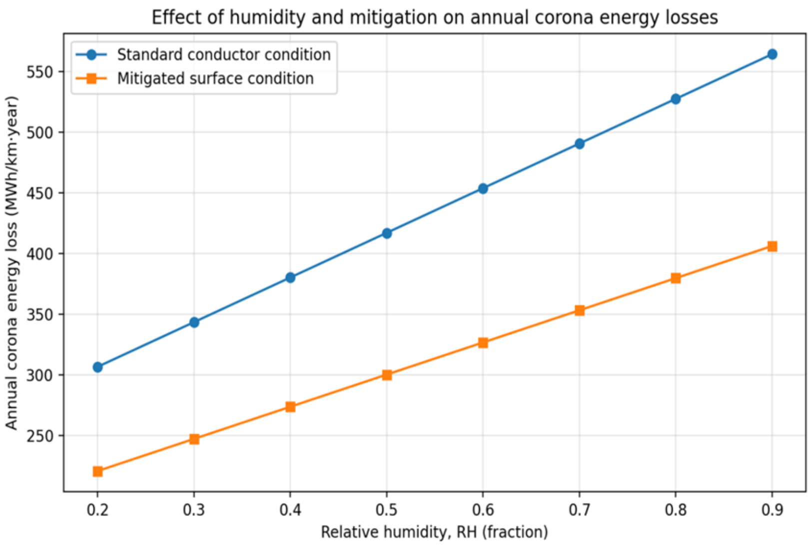

Figure 5. Effect of relative humidity and mitigation measures on annual corona energy losses

Table 1.
Electric field distribution

Distance (m)	E_{ns0} (V/m)	E_{ns1}	E_{ns2}	E_{ns3}	E_{ns4}	E_{ns5}
-100	120	120	120	120	120	120
-60	164	164	164	164	164	164
-40	187	187	187	187	187	187
-20	317	275	252	238	228	219
-10	1177	928	790	707	651	596
0	1900	1450	1200	1050	950	850
10	1177	928	790	707	651	596
20	317	275	252	238	228	219
40	187	187	187	187	187	187
60	164	164	164	164	164	164
100	120	120	120	120	120	120

Table 2.
Corona power and energy loss

Voltage (kV)	Corona Power Loss (kW/km)	Annual Energy Loss (MWh/km·year)
120	0	0
140	24	210
160	96	841
180	216	1892
200	384	3365
220	600	5256

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In contrast to traditional uniform maintenance strategies, the presented approach supports condition-based and optimization-oriented decision-making. By evaluating multiple mitigation actions using cost–benefit criteria, the method enables the selection of the most effective corrective measures under technical and budgetary constraints.

V. CONCLUSION AND FUTURE WORK

This study demonstrated that methyldiethanolamine (MDEA) waste, a byproduct of natural gas processing, can be effectively utilized as a functional modifier for 60/90 penetration-grade road bitumen. The incorporation of MDEA waste at optimized levels significantly enhanced the physicochemical and rheological performance of bitumen, particularly in terms of adhesion to aggregates, tackiness, viscosity, softening point, and thermal stability. Comparative results for different voltage levels (110 kV, 220 kV, and 500 kV) confirm that corona-related energy losses increase rapidly with voltage escalation, highlighting the necessity of advanced monitoring and targeted mitigation for extra-high-voltage transmission systems.

Table 3.
Effect of humidity and mitigation

Relative Humidity	Power Loss Standard (kW/km)	Power Loss Mitigated (kW/km)	Annual Energy Loss Standard (MWh/km·year)	Annual Energy Loss Mitigated (MWh/km·year)
0.30	35	25	307	219
0.40	42	30	368	263
0.50	50	36	438	315
0.60	58	42	508	368
0.70	66	48	578	421
0.80	74	53	648	464

The feedback loop based on before-and-after verification under comparable weather conditions ensures continuous refinement of model parameters and maintenance strategies. Overall, the proposed diagnostic, mathematical, and algorithmic framework provides a practical and scalable solution for reducing corona-induced power losses and improving the energy efficiency and operational reliability of high-voltage overhead transmission lines. The obtained results can be effectively applied to both existing transmission networks and the design of new lines, contributing to sustainable and efficient electric power transmission. Corona discharge is one of the fundamental physical phenomena affecting the efficiency and operational reliability of high-voltage overhead transmission lines. It occurs when the electric field intensity at the conductor surface exceeds the critical disruptive gradient of air, leading to partial ionization of the surrounding medium. Under such conditions, electrical energy is dissipated in the form of light emission, heat, acoustic noise, and electromagnetic interference, resulting in measurable power and energy losses. The initiation of corona discharge is governed primarily by the surface electric field strength, which depends on the line voltage, conductor radius, surface condition, phase spacing, and atmospheric parameters such as air density, humidity, and pressure. For a cylindrical conductor, the surface electric field increases with operating voltage and decreases with increasing conductor radius. Consequently, high-voltage transmission lines operating at 220 kV, 500 kV, and above are particularly susceptible to corona losses, especially under adverse weather conditions. From a physical perspective, corona-induced power losses are strongly nonlinear with respect to voltage. Below the corona inception voltage, losses are negligible; however, once the critical threshold is exceeded, the losses increase rapidly due to intensified ionization processes in the air. This nonlinear behavior makes corona discharge a limiting factor in the optimization of transmission voltage levels and conductor design. Moreover, surface irregularities, aging, contamination, and mechanical damage further enhance local electric field intensities, accelerating corona development even at nominal operating voltages. Theoretical models of corona losses traditionally relate the dissipated power to the difference between the operating voltage and the corona onset voltage. These models demonstrate that corona losses are proportional to the square or higher-order functions of this voltage difference, reflecting the underlying ionization mechanisms. While such analytical formulations provide valuable insight, their accuracy is limited under real operating conditions due to the stochastic nature of atmospheric influences and conductor surface degradation.

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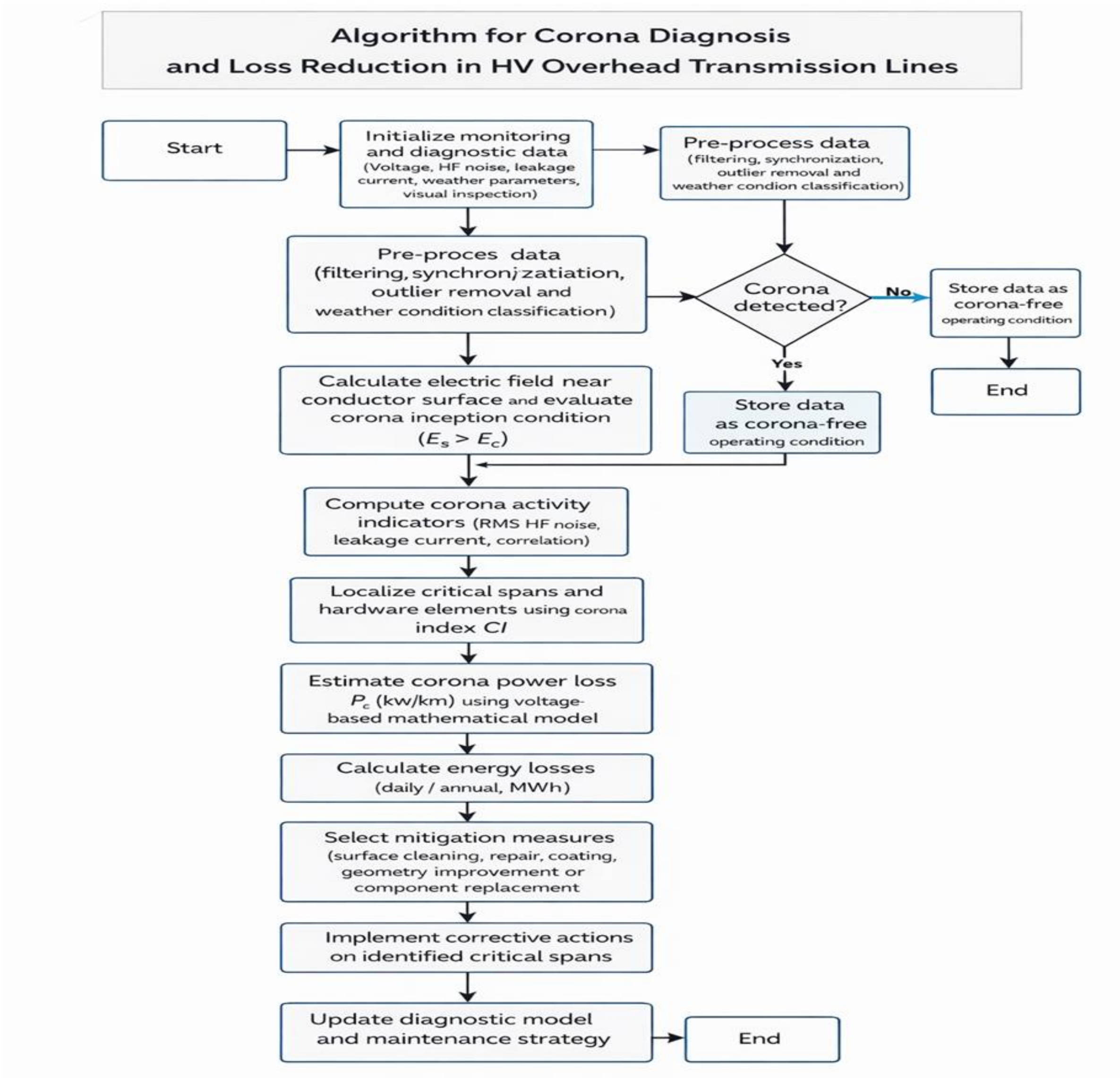

Figure 6. Algorithm for corona diagnosis and loss reduction in high-voltage overhead transmission lines

In modern power systems, diagnostic and monitoring technologies play a crucial role in refining the theoretical assessment of corona-induced losses. Continuous measurement of electrical parameters, high-frequency electromagnetic emissions, leakage currents, and meteorological data enables the real-time identification of corona-active operating regimes. By correlating diagnostic indicators with theoretical loss models, it becomes possible to localize critical line sections and quantify actual power and energy losses with higher precision. The reduction of corona-induced losses is theoretically achieved by lowering the surface electric field intensity or mitigating the conditions that promote ionization. This can be accomplished through optimized conductor geometry, increased effective conductor radius, improved surface condition, and targeted maintenance strategies. From a systems perspective, the integration of diagnostic results into loss models allows for adaptive optimization, where mitigation measures are applied selectively to the most critical spans rather than uniformly across the entire line. Thus, the theoretical foundation of corona loss reduction is based on the interaction between electromagnetic field theory, atmospheric physics, and power system diagnostics. By combining classical corona theory with modern monitoring data, it is possible to develop more accurate loss estimation models and implement effective strategies for improving the energy efficiency and reliability of high-voltage overhead transmission lines.

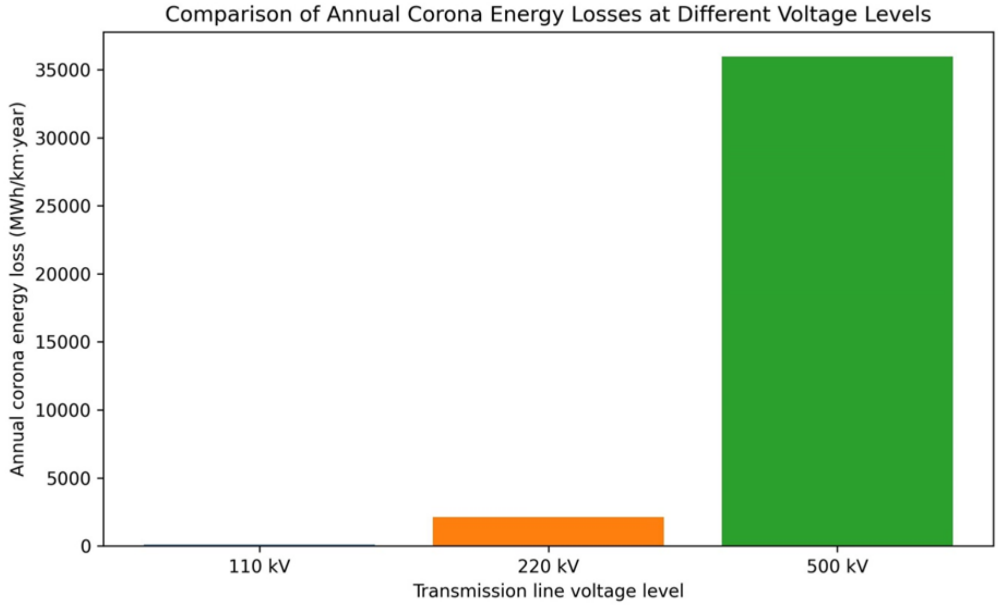

Figure 7. Comparison of annual corona-induced energy losses at different transmission voltage levels

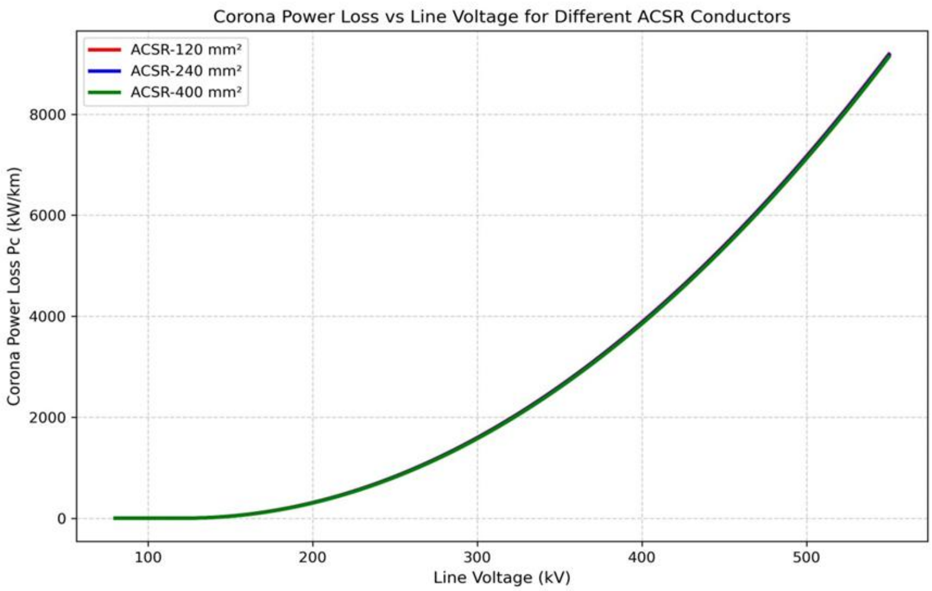

Figure 8. Corona power loss as a function of line voltage for different standard ACSR conductors

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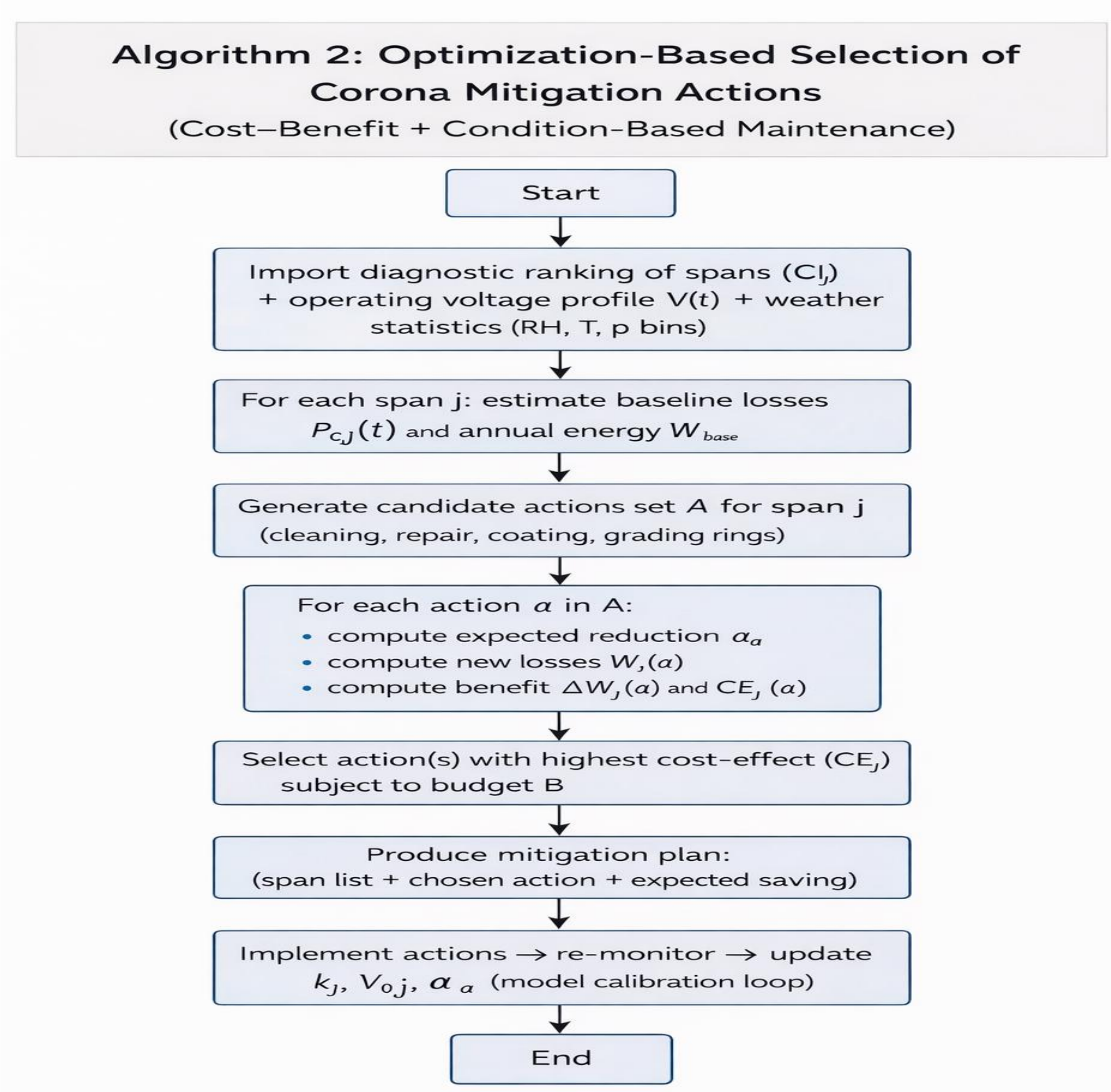

Figure 9. Optimization-based algorithm for the selection of corona mitigation actions in high-voltage overhead transmission lines

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