

Hybrid Multi-Objective Optimization of Overhead Power Lines using Boundary Elements, Genetic Algorithm and Goal Attainment Method

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This paper proposes a numerical approach aimed at reducing the fields generated by overhead power lines. The methodology combines the boundary element method for field evaluation with a multi-objective hybrid algorithm for field optimization, while ensuring compliance with critical non-linear design and safety constraints. The goal is to determine optimal configurations for the phase conductors that reduce electric field intensities at the conductor surface and minimize field magnitudes at ground level. The key innovation is the hybrid optimization approach, which combines an enhanced elitist genetic algorithm with the goal attainment method to navigate the multiple objectives and their constraints. A further unique aspect of this work is the minimization of the electric field at the conductor surface as one of the explicit optimization objectives. The resulting optimized configurations demonstrate reductions in field magnitudes without violating any specified constraints. Moreover, the hybrid approach outperforms the enhanced multiobjective algorithm, offering improved computational efficiency.

Index Terms—power lines, multiobjective programming, boundary element methods, genetic algorithms, goal attainment method.

I. INTRODUCTION

Research into new and optimized power line designs relies heavily on the computation and analysis of their electromagnetic field distributions [1]. Analytical approaches, however, while useful in idealized scenarios, can become impractical or overly complex when accounting for real-world factors such as the actual geometry of the cables or the influence of nearby electromagnetic devices. Consequently, there is a clear need to explore approximate solutions using numerical methods, which provide more accurate field calculations compared to traditional analytical simplifications [2].

The boundary element method (BEM) is a powerful numerical technique for analyzing electromagnetic interactions in unbounded domains, such as those surrounding overhead power lines. By naturally incorporating far-field boundary conditions, BEM eliminates the need for meshing the open-air region, drastically reducing the number of unknowns compared to domain methods like the finite element method. This leads to faster computations and lower memory usage, making BEM an efficient and robust tool for electromagnetic field analysis in power line scenarios, offering advantages over traditional analytical and numerical methods used in optimization [2].

The application of optimization techniques is necessary for the development of enhanced power line designs. The genetic algorithm (GA) and its variants are classical tools for addressing the numerous objectives and constraints inherent in power line design, such as electric field limits, conductor surface temperatures, induced fields, radio interference, audible noise control, insulation coordination, shield wire placement for lightning protection, and management of installation costs, among others [3], [4], [5].

However, multi-objective genetic algorithms are often computationally slow, particularly in the context of power line optimization, which typically involves many decision variables (and therefore large populations), objectives, and constraints. To speed up the solution process, a two-stage approach can be

employed. In this paper, we propose a hybrid constrained multi-objective optimization approach that combines an enhanced elitist genetic algorithm with the goal attainment method (GAM). This hybrid approach has not been explored in the context of power lines, making a distinct contribution to the field. The objectives of the optimization are to minimize both the electric field profiles at the conductor surface and at ground level, subject to the electric and geometric constraints of the power line. The optimized configurations achieved through this method exhibit significant reductions in electric field magnitudes while adhering to all constraints. Furthermore, the proposed hybrid approach outperforms the enhanced multiobjective genetic algorithm (MOGA), demonstrating improved computational efficiency.

II. OPTIMIZATION

Two optimization objectives are addressed: first, minimizing the electric field profile at the surface of the conductors, and second, minimizing the electric field profile at ground level. To achieve these goals, the first objective function is defined as the sum of the electric field intensities across the surfaces of all conductors. The second objective function represents the sum of the electric field magnitudes at all observation points at ground level. Fields are calculated using the BEM, as outlined in [2]. The optimization process is subject to constraints, including the distances between the conductors and the horizontal and vertical boundaries within which their positions may vary to optimize the field distributions [1], [2], [5].

In the context of the genetic algorithm, we propose a controlled elitist genetic algorithm, a variant of the Nondominated Sorting Genetic Algorithm II. While a standard elitist GA prioritizes individuals with superior fitness (rank), the controlled elitist MOGA additionally emphasizes individuals that contribute to maintaining or enhancing population diversity, even if their fitness is comparatively lower [6].

The goal attainment method employs a set of design goals, each linked to specific objectives. The formulation of the problem permits objectives to be either underachieved or overachieved, with the goals being regulated by a vector of weighting coefficients. This weighting vector provides the designer with a means to quantify the relative trade-offs between competing objectives [7].

To speed up the process, a two-stage approach is employed. Initially, MOGA runs for a limited number of generations and greater tolerance to obtain a rough approximation of the Pareto front. Subsequently, the GAM is applied, using the solutions generated by the MOGA as initial points for a more efficient solver. This hybrid approach allows for continued refinement of the initial solutions, speeding up the optimization process by leveraging the strengths of both algorithms.

III. RESULTS

To test the hybrid approach, a 138 kV three-phase power line configuration with a single conductor per phase is analyzed. The radius of the conductors is 0.01598 m. The following geometric constraints are considered: a minimum phase-to-phase distance of 1.50 m; horizontal limits of -3.00 m and 3.00 m for the left and right sides, respectively; and vertical limits of 15.01 m and 13.01 m for the top and bottom, respectively.

The original and optimized configurations are presented in Fig. 1. In both optimized setups, a near-delta arrangement is observed, with the lateral phase cables moved toward the upper boundary, while the central phase cable is displaced toward the lower boundary.

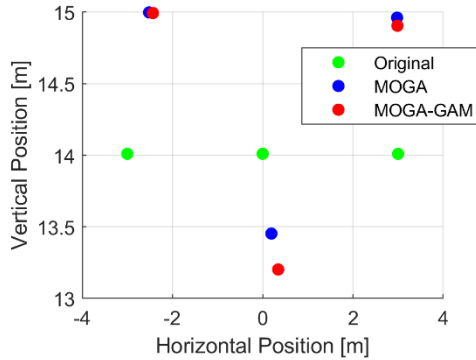


Fig. 1. Original and optimized designs.

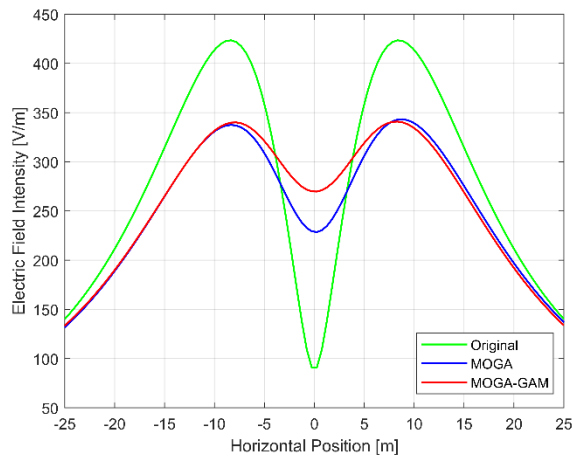


Fig. 2. Original and optimized electric field intensities at ground level.

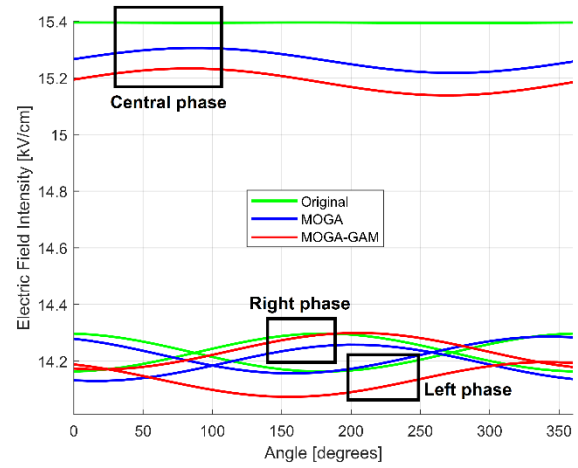


Fig. 3. Original and optimized electric field intensities at the surface of the conductors.

Figure 2 shows the electric field profiles at a height of one meter above the ground, spanning from -25 m to 25 m, for both the original and optimized designs. The results indicate a notable reduction of approximately 20% in the peak electric field values for both optimized configurations.

Figure 3 displays the electric field distributions at the surface of the conductors, both for the original and optimized configurations. The results demonstrate that the delta configurations also minimize electric field intensities on the conductors, with the hybrid method outperforming the enhanced MOGA in terms of the plotted solution.

Moreover, the hybrid optimization method ran approximately 10% faster on average compared to the enhanced MOGA. This performance improvement suggests that the hybrid method could be effectively applied to more complex scenarios, such as those involving more objectives or multiple conductors per phase.

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