OPTIMAL ELECTRIC FIELD PERFORMANCE OF EHV TRANSMISSION LINES USING GROUND SHIELD CONDUCTORS

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Abstract: Assessment and mitigation of the environmental impact of EHV power lines is a subject of current research due to the possible associated health hazards. The electric field beneath the line and the field on the conductor surface are known to be main sources of concern from an environmental standpoint. The present approach serves as means of reducing the electric field under EHVAC lines using ground shield wires. The aim is to determine the optimal ground shield wire heights and clearances to satisfy a set of field limitations on the conductors as well as on the ground. Genetic Algorithms, GAs, are employed to arrive at the required optimal clearances through an appropriate fitness function. The merits of the proposed approach are demonstrated for 3-phase horizontally-arranged 500kV single circuit transmission line. Results show the effectiveness and accuracy of the proposed approach.

1 INTRODUCTION

Environmental performance of high voltage power lines has been the target of various research studies over the last few decades [1-8]. Field effects and corona-generated audible and radio noise are among the most important aspects that have to be addressed when assessing the line impact on its neighbouring environment. Recent biological studies on electric and magnetic field effects have largely enhanced concern of possible health hazards to nearby living species [1-8]. Trends towards higher transmission voltages, with possibly increased field and interference levels, are contributing to such concerns.

Several techniques may be applied to reduce electric and magnetic fields such as reverse phase, split phase, shielding with loops or materials and underground cabling [1,3,4,7]. In general, shielding of the electric field can be achieved by simply introducing conductive material into the field [1,3,4]. It should be noted that cost and electrical performance of the line strongly dictate the technique to be applied for field reduction. For example, depending on the desired field level, line compaction (bringing the conductors of the power line closer to each other) may be applied. However, this technique is limited as compaction, in turn, affects other electrical parameters, important to the safe and effective operation of the line [4].

Although magnetic field reduction, to a certain extent, can be achieved by line compaction, special designs are required to reduce magnetic fields significantly [9,10]. An important technique which, generally, results in exceptional electric field reduction(may reach 10 times) while being low in cost (less than 10% of the line cost) is to use a wire mesh bonded to earth, called ground shield wires, and supported by wooden poles covering the area that needs to be shielded [3,4]. This approach is suitable as small areas can be shielded at relatively low cost and is feasible for local applications in spite of its possible visual impact [3,4]. This technique may be very effective for electric field reduction which is further investigated in the present work.

Electric field, E_g, beneath the line, usually 1 m above the ground, is influenced by the line voltage, the phase-to-phase spacing s, the line height h beside the ground shield wires height H_g, and their spacing S_g. Audible noise, tv and radio interference are by-products of the conductors corona discharges; that occur when the electric field at the conductor surface E_c exceeds a certain critical value. In addition to the voltage V, E_c is also dependent on the above dimensions. In summary, the electrical field environment of the line may be characterized by the presence of the both fields with the ground shield wires height H_g, and their spacing S_g as well as other related dimensions influencing their values and distributions. Determination of such dimensions is usually subject to various electrical, mechanical, economical, as well as environmental design considerations [5]. Extensive computational and studies over a relatively long period of time are necessary to meet the various requirements of the line design [5].

In this paper, a new approach to the determination of the ground shield wires height H_g, and their spacing S_g on primarily environmental basis is proposed. The maximum, E_{gm}, of the electric field distribution at ground as well as the maximum, E_{cm}, of the electric field at the conductor surface are targeted as a set of parameters that is indicative of the line impact on its environment. The aim is to determine these clearances H_g and S_g as well as related dimensions such that a prerequisite set of E_{cm} and E_{gm} appears in the line environment This should provide a considerable saving in the efforts for proper selection of these dimensions and/or the comparative studies of alternate line designs from an environmental standpoint. It is assumed that all variables other than the design of the dimensions H_g and S_g have been determined by other considerations.

Genetic algorithms computational schemes are employed in the present work to determine, directly and accurately, the H_g and S_g values as well as other related dimensions through the optimization of a relevant fitness function. A genetic model is developed for this purpose. The results of the simulation demonstrate the effectiveness and accuracy of the proposed approach.

2 FIELD PROFILES OF EHV LINES

Overhead transmission lines generate an electrostatic field that introduces design considerations in order to avoid excessive charging currents, induced voltages, or other undesirable effects, and to evaluate possible interactions between such effects and the environment. These effects are mainly dependent on the prevailing electric field beneath the line [5]. The peak electric field is usually taken as a design quantity for each of the possible effects.

The case considered consists of a 3-phase horizontally-arranged 500kV single circuit transmission line shown in Figure 1. The phase conductor consists of 2x30 mm diameter sub-conductors and 47 cm sub-conductor spacing. The phase angle of the middle conductor voltage is taken as the reference. The number of ground shield wires under each phase, N_g, is 3 each of diameter 15 mm. S_g is the spacing between the ground shield wires and H_g is the height.

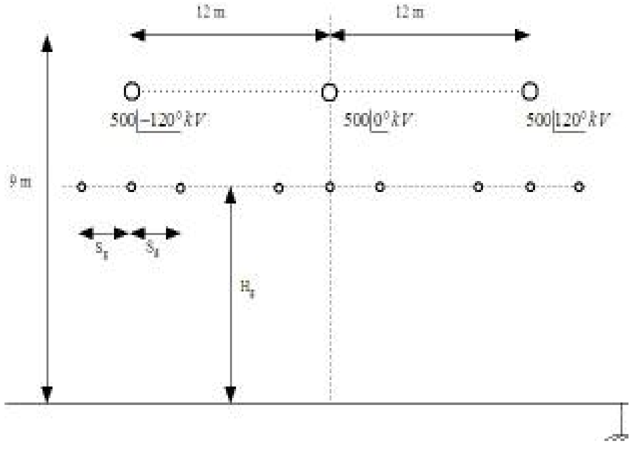

Figure 1: A 500kV single circuit horizontal HVAC transmission line model with 3 ground shield wires

Figure 2 shows the lateral field distributions for a 3-phase, horizontally-arranged, 500kV single circuit transmission line with and without ground shield wires. The lateral distance x is measured from the line middle phase. The ground field distribution is symmetric around the center of the middle phase.

The maximum electric field at ground, E_{gm}, without ground shield wires is 10.18kV/m while the maximum electric field at the conductor surface E_{cm} is 21.23kV/cm.

The figure shows the effect of using the ground shield wires at different heights H_g for S_g = 0.5 m upon the electric field distribution on the ground. It is clear that the whole electric field ground profile underneath the line is significantly reduced when ground shield wires are used. E_{gm} decreases with increasing H_g; e.g. E_{gm} reduced by 45% for H_g = 6 m compared with no shield wires which shows the effectiveness of using the ground shield wires. It can be observed that distributions overlap as H_g changes and the distribution peak also changes both in value and location. E_{gm} decreases by 35% to 45% for H_g varying from 4m to 6m.

Some regularity staffs recommend a 1.6 kV/m as a maximum allowable electric filed at the edge of the right of way, ROW [6]. With this arrangement, it is found that the ROW is reduced by about 15% (for H_g equals 6 m) from 34 m to 29 m.

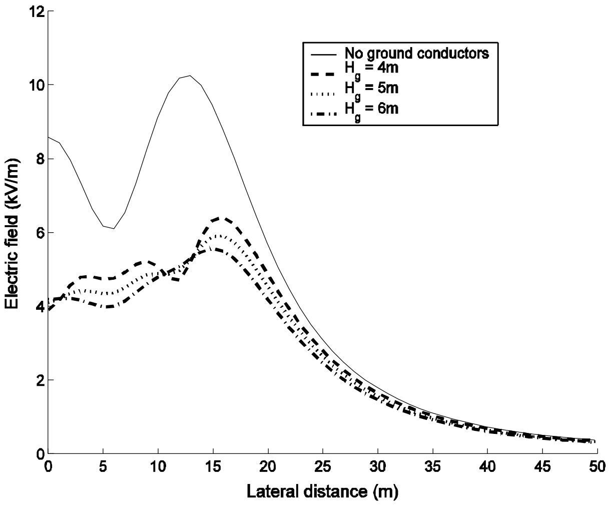

Figure 2: Lateral electric field profiles with & without ground shield wires (N_g =3, and S_g =0.5 m)

The influence of the ground conductors spacing S_g on the electric field distributions on the ground is shown in Figure 3. The Figure shows that E_{gm} decreases with increasing S_g. It can be seen that the distributions do not overlap and the peak value is less influenced than when H_g is changed. Variation of S_g from 0.5m to 1m results in reduction of E_{gm} and ROW by 7%.and 9% respectively.

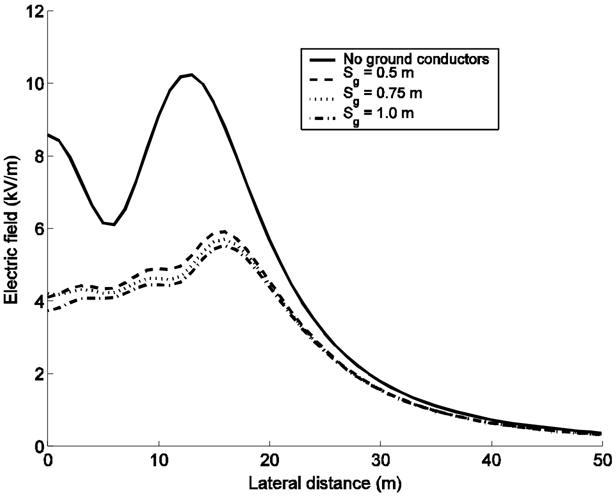

Figure 3: Lateral electric field profiles with & without ground shield wires (N_g =3, and H_g =5 m)

The variation of the maximum electric field at ground E_{gm} with S_g for different H_g is shown in Figure 4. E_{gm} decreases as S_g increases for the range of H_g considered with about 10%. For a certain S_g, the effect of varying H_g becomes less significant as H_g decreases.

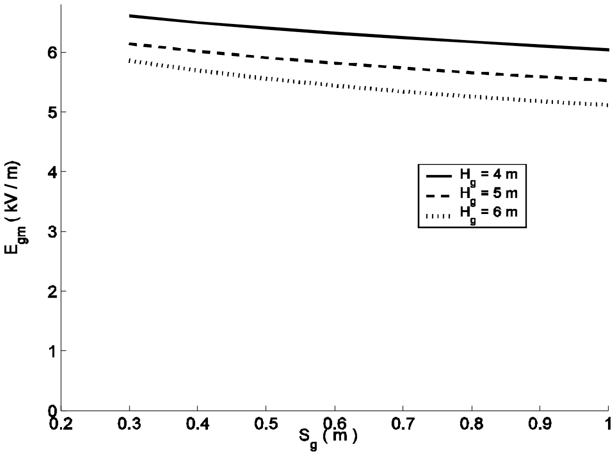

Figure 4: Variation of E_{gm} with S_g for different H_g

Corona effects are usually taken into account when deciding on the dimensions H_g and S_g. Generation of corona of a bundle conductor is practically determined by the maximum electric field at the surface of the sub-conductors [5].

The present analysis assumes a single equivalent smooth conductor per phase and that only the maximum conductor electric field is used as reference for the determination of the corona performance of the line conductors. Computations of the electric field showed that the maximum value of the electric field at the conductor surface, E_{cm}, always occur on the middle phase, while the maximum value of the electric field at the ground shield wires, E_{gcm}, always occur on the outer shield wire on both sides for a wide range of values of H_g and S_g.

Figure 5 shows the variation of E_{cm} and E_{gcm} with S_g for different H_g. After using the ground shield wires, E_{cm} increased by 7% at certain S_g and H_g equals 6 m compared with no shield wires It can be seen that E_{cm} increases as S_g increases for the range of H_g considered with about 1%. The influence of S_g becomes more significant for larger values of H_g. In general, for a certain H_g, it was observed that E_{cm} is less affected by the variation of S_g than E_{gm}. Also, Figure 5 shows that E_{gcm} increases as S_g increases for the range of H_g considered by 16%. The influence of S_g becomes more significant for larger values of H_g.

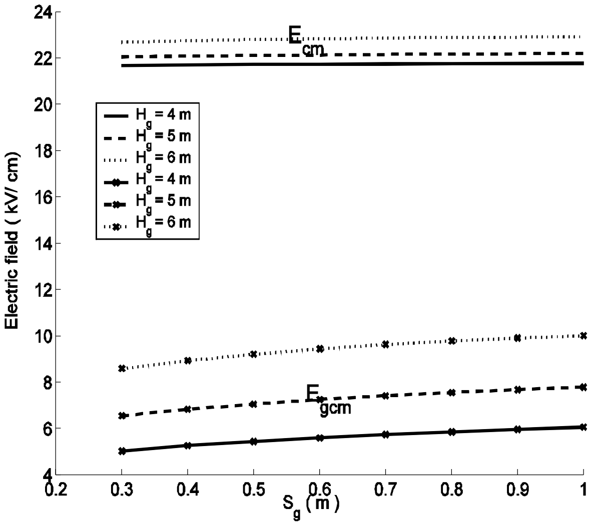

Figure 5: Variation of E_{cm} and E_{gcm} with ground conductors spacing for different H_g

The variation of the maximum electric field at ground E_{gm} with H_g for different S_g is shown in Figure 6. E_{gm} decreases as H_g increases for the range of S_g considered with about 25%. For a certain H_g, the effect of varying S_g becomes less significant as S_g increases.

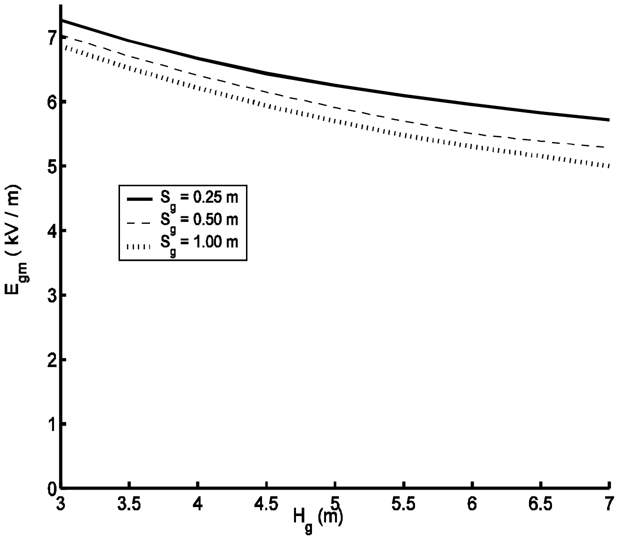

Figure 6: Variation of E_{gm} with ground conductors' height for different S_g

Figure 7 shows the variation of E_{cm} and E_{gcm} with H_g for different S_g. It can be seen that E_{cm} increases as H_g increases for the range of S_g considered by about 11%. The influence of H_g becomes more significant for larger values of S_g. In general, for a certain S_g, it was observed that E_{cm} is less affected by the variation of H_g than E_{gm}. Also, Figure 7 shows that E_{gcm} increases as H_g increases for the range of H_g considered. The influence of H_g becomes more significant for larger values of S_g.

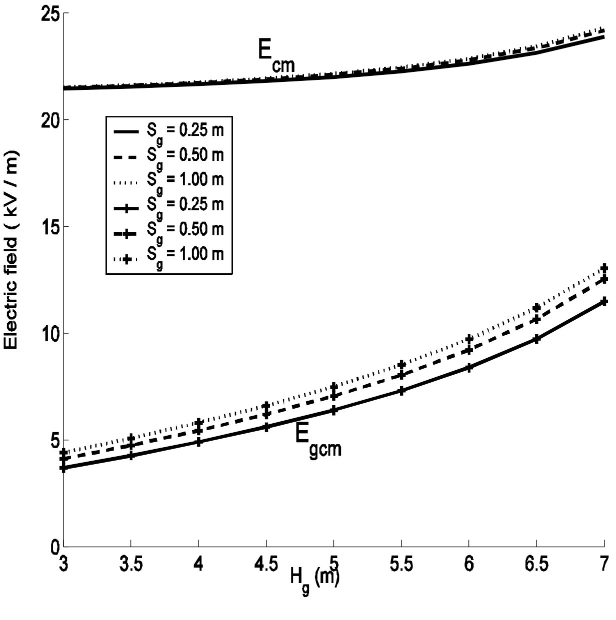

Figure 7: Variation of E_{cm} and E_{gcm} with ground conductors height for different S_g

This discussion demonstrates that; from an environmental standpoint, the field values E_{cm} and E_{gm} can be considered as single set of indicators of the environmental impact of a power line with the ground shield wires dimensions H_g and S_g controlling their variations, while the field values E_{gcm} does not present a problem of the design as their values are lower than the corona field values.

3 GENETIC ALGORITHMS

Genetic algorithms are search and optimization techniques based on the theory of natural selection [11-13]. An initial population of a constant size is created from a random selection of the parameters in the parameter space. Each parameter set represents the individual's chromosome. Each of the individuals is assigned a fitness value based on how well each individual chromosome allows it to perform in its environment.

Three basic operations occur in GAs to create the next generation: Selection, Crossover and Mutation. More fit individuals are selected for mating while less fit ones diminish. Parents create a child, through the crossover operation, with a chromosome set that is some mix of the parents' chromosomes. Then there is a small probability that one or more of the child's chromosomes will be mutated; thus introducing new individual into the population. The process of mating and child creation is continued until an entirely new population of the same size is generated.

Improvement in the selection scheme can be achieved by introducing elitism into the selection process. The elitist strategy copies the best member of each generation into the succeeding generation. This strategy may increase the speed of domination of a population by a super individual and thus improve the search at the expense of a global perspective, but on balance it tends to improve the GA performance [11-13]. The above genetic operators are implemented in the present analysis.

4 TRANSMISSION LINE MODELING

In order to demonstrate the merits of the proposed approach, the above 3-phase horizontally-arranged 500kV single circuit transmission line is modelled. The dimensions to be optimized are the ground shield wires height H_g, and their spacing S_g. Each parameter is coded as a 15-bit binary string; thus the chromosome length is 30 bits. The error is expressed as follows:

$$\text{Error} = 0.5*[\text{abs}(E_{cmo} - E_{cm}) + \text{abs}(E_{gmo} - E_{gm})] \quad (1)$$

where E_{cmo} and E_{gmo} are the pre-specified maximum conductor surface field and the peak electric field at ground respectively. The fitness function to be maximized is given by:

$$\text{Func} = \max\left[\frac{1}{1 + \text{error}}\right] \quad (2)$$

The number of generations used in the simulation is 2000 and the population size is 5. The crossover probability is 0.5 and the mutation rate is 0.02. A practical search space for S_g is taken to lie between 0.4 m and 0.8m cm while that for H_g is between 4 and 6 m.

Table 1 summarizes the simulation results in this case. A practical range for both E_{gmo} and E_{cmo} is selected for the simulation [5-7]. However, it should be noted that any other value for either E_{gmo} or E_{cmo} could be used as well as all conductors are assumed to be smooth with surface roughness factor of one. When calculating E_{gm} and E_{cm} using the optimal H_g and S_g values, the accuracy of them is found acceptable. It can be seen that as E_{cmo} increases, for a given E_{gmo}, both H_g and S_g increases. However, the change in S_g is much more pronounced than that of H_g. Also, as E_{gmo} varies, for a given E_{cmo}, S_g varies more significantly than H_g. The results demonstrate the effectiveness of the present approach.

Table 1: Results of the simulation

E_{gmo} (kV/m)	E_{cmo} (kV/cm)	H_g (m)	S_g (m)
5	21	4.81	0.64
	22	4.83	0.71
6	21	4.32	0.52
	22	4.36	0.58
7	21	4.01	0.41
	22	4.05	0.45

5 CONCLUSION

A new approach to mitigate electric field under EHV power lines using ground shield wires has been presented. The maximum electric field at the ground level E_{gm} and the ROW width was reduced using the proposed technique. The influence of increasing the shield wires height H_g on the reduction of E_{gm} was found to be more effective than increasing the shield wires spacing S_g. On the other hand, the influence of decreasing the shield wires height H_g on the reduction of E_{cm} and E_{gcm} was less effective than decreasing the shield wires spacing S_g. The proposed genetic algorithm scheme offer flexibility, efficiency as well as accuracy for the determination of the optimal ground shield wires height and spacing as well as other related dimensions so that a pre-specified set of field values will not be exceeded in the line environment. A 3-phase horizontally-arranged 500kV single circuit transmission was studied. The results of the simulation demonstrated the effectiveness and accuracy of the proposed approach.

6 REFERENCES

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