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THE DETERMINATION OF THE DISTANCE BETWEEN THE CONDUCTORS IN BUNDLED CONDUCTOR USED IN HIGH VOLTAGE TRANSMISSION LINES BY USING SIMULATED ANNEALING

ABSTRACT

The most suitable value of distance between the conductors in bundled conductor is necessary that used in high voltage transmission lines. The maximum electric field when corona loss started in the high voltage line system was calculated by mathematical equation analysis. In this study, the distance between the conductors in bundled conductor have been determined by using Gauss Seidel (GS) of numeric analysis methods and Simulated Annealing (SA) of heuristic methods with mathematical equations. Results taken with both methods have been compared to each other. According to results of SA to GS, it has been seen the better %0.0117, %0.0012, %0,0061, in 220, 380 and 500 kV values respectively.

Keywords: Power Systems, Bundled Conductor, Optimization, Simulated Annealing, Gauss Seidel

YÜKSEK GERİLİM HATLARINDA KULLANILAN DEMET İLETKEN İÇİNDEKİ İLETKENLER ARASI MESAFENİN TAVLAMA BENZETİMİ KULLANILARAK BELİRLENMESİ

ÖZET

Yüksek gerilim hatlarında kullanılan demet iletken içindeki iletkenler arası mesafenin en uygun değerde olması gerekmektedir. Yüksek gerilim hatlarında korona kayıpları başladığında elektrik alanı maksimum olmakta ve matematiksel denklemlerin analizi ile hesaplanmaktadır. Bu çalışmada matematiksel denklemler ile demet iletken içindeki iletkenler arası mesafe nümerik analiz yöntemlerinden biri olan Gauss Seidel (GS) ve sezgisel metotlardan biri olan Tavlama Benzetimi (TB) kullanılarak belirlenmiştir. Her iki metot da bulunan sonuçlar karşılaştırılmıştır. Sonuçlara göre SA' nın GS' ye 220, 380 ve 500 kV değerlerinde sırasıyla %0.0117, %0.0012, %0,0061 daha iyi sonuçlar verdiği görülmüştür.

Anahtar Kelimeler: Güç Sistemleri, Demet İletken, Optimizasyon, Tavlama Benzetimi, Gauss Seidel

1. INTRODUCTION (GİRİŞ)

Corona loss occurs on transmission line when the voltage gradient in the immediate vicinity of the conductor surface exceeds the breakdown strength of air [1 and 2].

For voltage in excess of 230 kV it is in fact not possible to use a round single conductor. Instead of going in for a hollow conductor it is preferable to use more than one conductor per phase which is known as bundling of conductors. A bundle conductor is a conductor made up of two or more sub-conductors and is used as one phase conductor. It is found that the increase in transmission capacity justifies economically the use of two conductor bundles on 220 kV lines. When bundled conductor use, the advantages reduced reactance, reduce voltage gradient, reduce corona loss, reduce radio interference, reduce surge impedance and allows for an increase in power transmission line [3, 4, and 5]. Ozturk et al utilized genetic algorithm to calculate the distance between the conductors in bundled conductor used in high voltage transmission line[6].

As a result distance between the conductors in bundled conductor have been evaluated by GS and SA.

2. RESEARCH SIGNIFICANCE (ÇALIŞMANIN ÖNEMİ)

In this study distance between the conductors in bundled conductor has been calculated used in high voltage transmission line in electrical power systems. It has been aimed to compare GS and SA in problem. When distance between the conductors in bundled conductor decrease, the advantages reduced reactance, reduce voltage gradient, reduce corona loss, reduce radio interference, reduce surge impedance and allows for an increase in power transmission line. As a result distance between the conductors in bundled conductor have been evaluated by GS and SA.

3. GAUSS SEIDEL (GAUSS SEIDEL)

The Gauss-Seidel method is a technique for solving the n equations of the linear system of equations $Ax = b$ one at a time in sequence, and uses previously computed results as soon as they are available.

$$x_i^{(k)} = \frac{b_i - \sum_{j<k} a_{ij} x_j^{(k)} - \sum_{j>i} a_{ij} x_j^{(k-1)}}{a_{ij}} \quad (1)$$

There are two important characteristics of the Gauss-Seidel method should be noted. Firstly, the computations appear to be serial. Since each component of the new iterate depends upon all previously computed components, the updates cannot be done simultaneously as in the Jacobi method. Secondly, the new iterate $x^{(k)}$ depends upon the order in which the equations are examined. If this ordering is changed, the components of the new iterates (and not just their order) will also change.

In terms of matrices, the definition of the Gauss-Seidel method can be expressed as Eq.2;

$$x^{(k)} = (D - L)^{-1}\left(Ux^{(k-1)} + b\right) \quad (2)$$

Where the matrices **D**, **-L**, and **-U** represent the diagonal, strictly lower triangular, and strictly upper triangular parts of **A**, respectively.

The Gauss-Seidel method is applicable to strictly diagonally dominant, or symmetric positive definite matrices **A** [7, 8, and 9].

4. SIMULATED ANNEALING (TAVLAMA BENZETİMİ)

Early simulated annealing algorithms considered combinatorial systems, where the system's state depends on the configuration of variables. Perhaps the best known is the traveling salesman problem, in which one tries to find the minimum trip distance connecting a number of cities [10].

The SA was proposed by Kirkpatrick et al. [11] to deal with complex non-linear problems. They showed the analogy between simulating the annealing of solid as proposed by Metropolis et al. [12]. The SA is an iterative improvement algorithm for a global optimization. The optimization process in SA is essentially a simulation of the annealing process of molten metals [13, 14, 15, and 16].

Annealing is cooled down slowly in order to keep the system of the melt in a thermodynamic equilibrium which will increase the size of its crystals and reduce their defects. As cooling proceeds, the atoms of solid become more ordered. If the cooling was prolonged beyond normal, the system would approach a "frozen" ground state at the lowest energy state possible. The initial temperature must not be too low and the cooling must be done sufficiently slowly so as to avoid the system getting stuck in a meta-stable state representing a local minimum of energy.

SA aims to find global minimum without got trapped local minimums. So if object function is a maximization problem, problem is converted minimization problem multiplying minus 1. The simulated annealing makes use of the Metropolis et al. [11] algorithm which provides an efficient simulation according to a probabilistic criterion stated as:

$$P(\Delta E) = \begin{pmatrix} 1, & if & \Delta E \langle 0 \\ e^{(\Delta E / T*k)}, & & otherwise \end{pmatrix}$$

Thus, if $\Delta E \langle 0$, the probability, P, is one and the change - the new point- is accepted. Otherwise, the modification is accepted at some finite probability. Each set of points of all atoms of a system is scaled by its Boltzmann probability factor $e^{-\Delta E / T*k}$ where ΔE is the change in the energy value from one point to the next, k is the Boltzmann's constant and T is the current temperature as a control parameter. The general procedure for employing the SA as follows;

Step 1: Start with a random initial solution, X, and an initial temperature, T, which should be high enough to allow all candidate solutions to be accepted and evaluate the objective function.

Step 2: Set i = i +1 and generate new solution $X_i^{new} = X_i + r * SL_i$ where r is random number and SL_i at each move should be decreased with the reduction of temperature.

Evaluate $F_i^{new} = F(X_i^{new})$

Step 3: Choose accept or reject the move. The probability of acceptance (depending on the current temperature) if $F_i^{new} \langle F_{i-1}$, go to Step 5, else accept F_i as the new solution with probability $e^{(\Delta E / T*k)}$, where $\Delta E = F_i^{new} - F_{i-1}$ new and go to Step 4.

Step 4: If F_i was rejected in Step 3, set $F_i^{new} - F_{i-1}$. Go to Step 5.

Step 5: If satisfied with the current objective function value, F_i, stop. Otherwise, adjust the temperature $T^{new} = Tr_T$ where r_T is temperature reduction rate called cooling schedule and go to Step 2. The process is done until freezing point is reached. The major advantages of the SA are an ability to avoid becoming trapped in local optimum and dealing with highly nonlinear problem with many constraints and multiple points of optimum [16].

5. DEFINING PROBLEM (PROBLEMİN TANIMLANMASI)

When the electric field in high voltage transmission lines are maximum, corona loss begins. The distance between the conductors in bundled conductor can be calculated by the mathematical equation which defines the electrical field. In this study, initially this distance value has been calculated by using GS method. Then the same value has been calculated with SA. 220 kV, 380 kV and 500 kV voltage values have been used for two, three and four bundled conductors. (a) and (r) values fixed, (d) value variable have been accepted as shown in Figure 1, Figure 2 and Figure3.

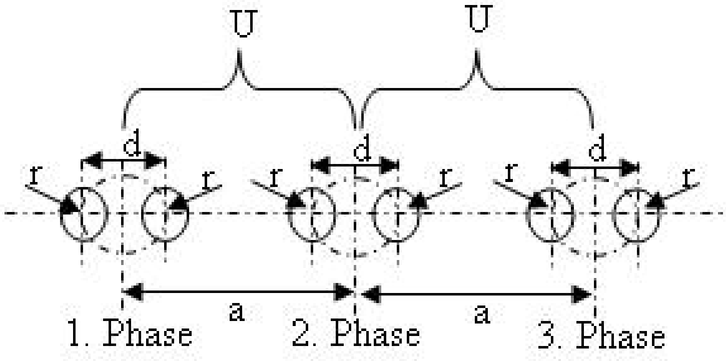

Figure 1. 3 Phase-2 bundled conductor a high voltage transmission line [5].
(Şekil 1. 3 faz 2'li demet iletkenli bir yüksek gerilim iletim hattı [5])

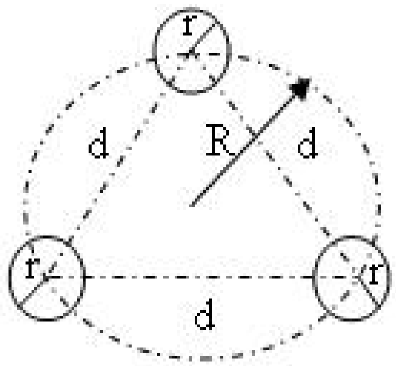

Figure 2. 3 Bundled conductor a high voltage transmission line [5].
(Şekil 2. 3'lü demet iletkenli yüksek gerilim iletim hattı [5])

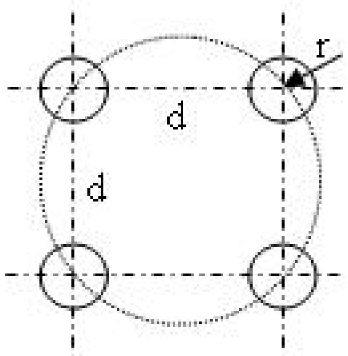

Figure 3. 4 Bundled conductor a high voltage transmission line [5]
(Şekil 3. 4'lü demet iletkenli bir yüksek gerilim iletim hattı [5])

(a) 3 phase between distance, (r) conductor radius,(d) distance between the conductors in bundled conductor.

5.1. Solution of the Problem with GS Method (GS Metodu İle Problemin Çözümü)

In this study, for Figure 1 and Figure 2 the same E^{max} equations have been done using GS method. For figure 1 initial value $d^{(0)} = 35$, fault value $\varepsilon = 0.5$, for figure 2 $d^{(0)} = 0.1$, fault value $\varepsilon = 0.02$, for figure 3 $d^{(0)} = 0.1$, fault value $\varepsilon = 0.01$ were accepted. In order to solve Gauss Seidel the last two iteration values must provide the condition of $\left| d^{n} - d^{n+1} \right| \le \varepsilon$ then the iteration is calculated.

Figure 1, Figure 2 and Figure 3 equations [5].

$$E_{\max} = \frac{U}{n * r * \ln\left(\frac{a}{R_e}\right)} * \left(1 + A * \frac{2 * r}{d}\right) \tag{3}$$

$$R_e = R * \sqrt[n]{\frac{r * n}{R}} \tag{4}$$

5.2. Solution of the Problem with SA (Problemin SA ile Çözümü)

Equation 5 has been used as object function to calculate the distance between the conductors in bundled conductor in Figure 1, Figure 2 and Figure 3 [5].

$$OF = E_{\max} = \frac{U}{n * r * \ln\left(\frac{a}{R_e}\right)} * \left(1 + A * \frac{2 * r}{d}\right) \tag{5}$$

$$R_e = R * \sqrt[n]{\frac{r * n}{R}} \tag{6}$$

A and R values which change according to the number of conductors used as goal function have been given in Table 1 [5]. In this study, parameters of SA in used solution of the problem have been given Table 2. The distance between the conductors in bundled conductor variable range was shown in Eq.7 [5].

Table 1. A and R values depend on bundled conductor of numbers
(Tablo 1. Demet iletken sayılarına bağlı A ve R değerleri)

n	A	R
2	1	d/2
3	1.73	$d/\sqrt{3}$
4	2.12	$d/\sqrt{2}$

Table 2. Parameters of SA in used solution of problem
(Tablo 2. Problemin çözümünde kullanılan SA parametreleri)

T (C)	r_T (rate cooling)	**k** (Boltzmann constant)
1*10^(25)	.93	1.380650524*10^(-23)

$$20 \le d \le 40 \tag{7}$$

6. CONCLUSIONS AND DISCUSSION (SONUÇLAR VE TARTIŞMA)

Consequently d values Figure 1, Figure 2 and Figure 3 have been found by SA and GS methods and they are shown in Table 3.

Table 3. Distance value between the conductors in bundled conductor
(Tablo 3. Demet iletken içindeki iletkenler arası mesafe değeri)

V(kV)	d Values Found with GA [6]		d Values Found with GS [6]		d Values Found with SA	
	d(cm)	E_{max} (kV/cm)	d(cm)	E_{max} (kV/cm)	d(cm)	E_{max} (kV/cm)
220	29.8071 [6]	14.7606 [6]	29.8091 [6]	14.7606 [6]	29.8056	14.7606
380	32.7277 [6]	20.0867 [6]	32.7282 [6]	20.0867 [6]	32.7278	20.0867
500	24.5079	28.8349	24.4991	28.8349	24.4976	28.8349

Ozturk et al. [6] was calculated the distance between the conductors in bundled conductor used in high voltage transmission line in 220 kV and 380 kV values. In this study, it has been aimed to accurately find the distance value between the conductors in bundled conductor in high voltage transmission line. As can be seen in the results, in different voltage values the d values have been obtained the more reliable and accurately. When results were examined, it can be calculated that by using SA, GS and GA methods, %100 of reliability can be provided to calculate the distance of conductor value. As it has been seen from the Table 3 that in 220 and 380 kV, SA performance is more effective to GA. SA performance is more effective to GS in 220,380 and 500 kV.

As a result both methods can be accepted as an alternative method used to calculate the distance between the conductors in bundled conductor in high voltage transmission lines.

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