

## ELECTRIC FIELD MITIGATION NEAR OVER HEAD POWER LINES USING VOLTAGE UNBALANCE

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### ABSTRACT:

A lot of people have to live near power lines, and there is strong evidence that electric fields around power lines may cause cancer as well as many other symptoms that humans can directly observe, such as poor short-term memory, chronic fatigue, depression, nausea, and rashes. Hence, it is necessary to mitigate these fields to acceptable values to protect such groups. There are already many conventional compensation techniques in electric field mitigation may be useful in areas where the space is available however in residence with high civil density other techniques should be introduced. In the present paper, the self-compensation using voltage unbalance will be introduced. The main concept of the research is that the electric field resulting from three-phase voltages is negligible as the separations among phases are too small. However, in Overhead Transmission Lines the separations among conductors are determined based on the breakdown strength of air and cannot be changed widely. On the other hand, this concept could be applied electrically not mechanically in

overhead power lines by controlling the three-phase voltages to make it as if it were located as near as possible to each other, resulting in a lower electric field. Genetic Algorithm (GA) is used to find the desired voltage unbalance achieving the electric field as minimum as possible in the residence area. The proposed algorithm is applied to 11 kV line and the results show that the electric field is reduced to about 82% under the safe limit, which is considered a very good percentage compared to other techniques.

### Keywords:

Voltage unbalance, electric field, genes, fitness, individuals, genetic algorithm, and mitigation techniques.

### Symbols & Abbreviations:

AC:	alternating current
ALS:	Amyotrophic Lateral Sclerosis
EHV:	Extra High voltage
EMF:	Electromagnetic field
EMF:	Electromagnetic Force
FDM:	finite difference method
FEM:	finite element method

GA:	Genetic algorithm
Hz:	Hertz (unit of measuring frequency)
kV:	kilovolt (units of measuring electromotive force)
PSO:	particle swarm optimization
RMS:	Root mean square
V/m:	Volt per meter (unit of measuring electric field)

## I-INTRODUCTION:

There is a modern term called "electric pollution", which refers mostly to the bad effects of electric and magnetic field energy emanating from electrical wiring. Many publications have dealt with this subject and discussed the harmful effects of electromagnetic fields on the human body depending on the frequency and intensity of the electromagnetic field. They concluded, "Chronic exposure to EMF is associated in some scientific studies with increased health risks that vary from headaches, skin rashes, mental confusion, tinnitus, impaired learning and disorientation to a variety of cancers, and neurological diseases like Amyotrophic Lateral Sclerosis (ALS) and Alzheimer's. Thus it is always a good idea to avoid the unnecessary exposure to electromagnetic fields whenever possible. [1, 2]. Although attention has focused on childhood cancer and leukemia in relation to exposure to EMF; other diseases including adult cancers, heart disease, Alzheimer's disease, the incidence of suicide, miscarriage, and depression have been investigated [3]. The limit for the undisturbed field for humans is 15 kV/m as RMS value [4]. When designing a transmission line this limit is not crossed. Also, proper care has been taken in order to keep minimum clearance between transmission lines [5].

There are different methods used to calculate the electric field around power lines. The boundary-dividing methods are preferred,

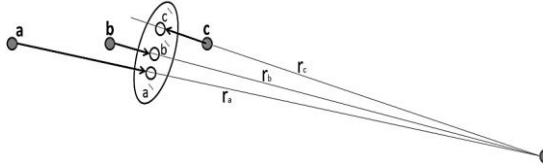
such as the finite difference method (FDM) or finite element method (FEM) [6]. Gaussian cubature method is an efficient numerical integration method that yields simple and fast potential and field formulas since the triangles and rectangles with their continuous charge distributions are replaced by discrete point charges. Thus this method is very accurate at positions far from the elements. However, for positions very close to the elements, the Gaussian cubature method is not precise enough, therefore analytical integration has to be used there [5, 7, 8].

Different methods are used to mitigate the electric field intensity near to power lines. These methods could be electrical or mechanical. The mechanical methods depend on changing positions of conductors such that the magnetic field is minimum. One of these methods is the transposition of overhead power line such that the desired values of electric and magnetic field mitigation are obtained [9]. But this method requires more than a line to find the optimal solution in addition to the best solution is restricted by discrete values of the field. Another mechanical method that is suitable for a single line method is adjusting the line geometrical parameters in order to achieve the minimum intensity of the electric field and magnetic field intensity the line [10]. The main disadvantages of this method are the high cost and the solution is restricted by the breakdown strength among phases [9, 11]. Also, active and passive shield wires are used to mitigate the electric field as an electrical method. The electric field at the ground level decreases continuously with the increase of the spacing between shield wires. The main disadvantage of this method is that it has no great effect around the line, its effect appears only under the line [10, 12].

The present paper provides a proof that inserting voltage unbalance into the power line

could be used to mitigate the electric field intensity to a very low level. Adjusting the voltage of each conductor within the allowable limits which not exceed than 10% of the rated voltage [13, 14], to make them seen as electrified by balanced three-phase voltage at positions close to each other resulting in a lower electric field.

Fig.1 shows a schematic diagram of the proposed method. In the proposed method GA is used to obtain the desired voltage unbalance causing the electric field intensity minimum value.

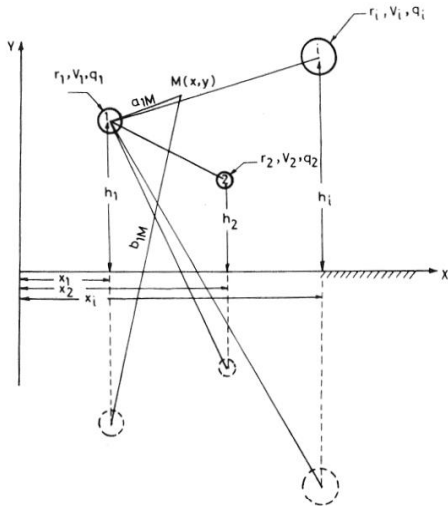


**Fig.1: Schematic of proposed method**

## II CALCULATION OF ELECTRIC FIELD

### *a- general case:*

A transmission line of long conductor parallel to the ground shown in Fig.2 consists of  $n$  conductors with potentials  $V_i$  and charges  $q_i$  per unit length ( $i = 1, 2, \dots, n$ ).



**Fig.2: Transmission-line conductors over the ground plane.**

The effect of the ground is simulated by mirror images of the charges  $q_i$  [15]. The potential  $\Phi_{M1}$  at an arbitrary point  $M(x, y)$  due to conductor 1 and its image assuming the line charge is located at the axis of each conductor is given by:

$$\Phi_{M1} = \frac{q_1}{2\pi\epsilon_0} \ln \frac{b_{1M}}{a_{1M}} \quad (1)$$

Where,

$a_{1M}$ : the distance between the conductor 1 and the selected arbitrary point  $M$

$b_{1M}$ : the distance between the image of the conductor 1 and the selected arbitrary point  $M$ .

A useful approximation is to consider that the line charge is located at the axis of each conductor, and to finish the calculations, ( $h_i$  - the height above the ground) & ( $r_i$  - the radius of the  $i$ th conductor) should be considered. The field at point  $M$  due to conductor 1 and its image is the gradient of  $\Phi_{M1}$  as follows:

$$\vec{E}_{M1} = - \frac{\partial \Phi_{M1}}{\partial x} \vec{u}_x - \frac{\partial \Phi_{M1}}{\partial y} \vec{u}_y \quad (2)$$

$$\vec{E}_{M1} = \frac{q_1(x-x_1)}{2\pi\epsilon_0} \left( \frac{1}{a_{1M}^2} - \frac{1}{b_{1M}^2} \right) \vec{u}_x + \frac{q_1}{2\pi\epsilon_0} \left( \frac{y-h_1}{a_{1M}^2} - \frac{y+h_1}{b_{1M}^2} \right) \vec{u}_y \quad (3)$$

Then the potential at point  $M$  due to all the transmission-line conductors could be given by:

$$\Phi_M = \sum_{i=1}^n \frac{q_i}{2\pi\epsilon_0} \ln \frac{b_{iM}}{a_{iM}} \quad (4)$$

Subsequently, the resultant field at point  $M$  has the following components:

$$(E_x)_M = \sum_{i=1}^n \frac{q_i(x-x_i)}{2\pi\epsilon_0} \left( \frac{1}{(x-x_i)^2+(y-h_i)^2} - \frac{1}{(x-x_i)^2+(y+h_i)^2} \right) \quad (5)$$

$$(E_y)_M = \sum_{i=1}^n \frac{q_i}{2\pi\epsilon_0} \left( \frac{y-h_i}{(x-x_i)^2+(y-h_i)^2} - \frac{y+h_i}{(x-x_i)^2+(y+h_i)^2} \right) \quad (6)$$

If the point M is placed on the first conductor, then

$$\phi_M = V, b_{1M} = 2h_1, a_{1M} = r_1$$

Finally, (4) takes the following form shown in (7).

$$V = \frac{q_1}{2\pi\epsilon_0} \ln \frac{2h_1}{r_1} + \frac{q_2}{2\pi\epsilon_0} \ln \frac{b_{12}}{a_{12}} + \frac{q_3}{2\pi\epsilon_0} \ln \frac{b_{13}}{a_{13}} + \dots + \frac{q_n}{2\pi\epsilon_0} \ln \frac{b_{1n}}{a_{1n}} \quad (\text{Eq. 7})$$

Using the matrix form, (Eq.,7) could be written as follows;

$$V_1 = q_1 P_{11} + q_2 P_{21} + q_3 P_{31} + \dots$$

$$V_2 = q_2 P_{12} + q_2 P_{22} + q_3 P_{32} + \dots$$

$$V_i = q_i P_{1i} + q_i P_{2i} + q_i P_{3i} + \dots$$

Finally, the previous equation could be introduced in the following matrix form:

$$[V] = [P] [q] \quad (8)$$

### ***b- Three-conductors case:***

For only 3-conductors line, the electric field could be calculated through the following steps:

#### **1- Calculating distance matrices [a],[b] & [P]**

$$[a] = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

$$= \begin{bmatrix} r_1 & \frac{\sqrt{(x_2-x_1)^2+(y_2-y_1)^2}}{r_2} & \frac{\sqrt{(x_3-x_1)^2+(y_3-y_1)^2}}{r_3} \\ \frac{\sqrt{(x_1-x_2)^2+(y_1-y_2)^2}}{r_1} & r_2 & \frac{\sqrt{(x_3-x_2)^2+(y_3-y_2)^2}}{r_3} \\ \frac{\sqrt{(x_1-x_3)^2+(y_1-y_3)^2}}{r_1} & \frac{\sqrt{(x_2-x_3)^2+(y_2-y_3)^2}}{r_2} & r_3 \end{bmatrix}$$

$$[b] = \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix}$$

$$= \begin{bmatrix} 2y_1 & \frac{\sqrt{(x_2-x_1)^2+(y_2+y_1)^2}}{2y_2} & \frac{\sqrt{(x_3-x_1)^2+(y_3+y_1)^2}}{2y_3} \\ \frac{\sqrt{(x_1-x_2)^2+(y_1+y_2)^2}}{2y_1} & 2y_2 & \frac{\sqrt{(x_3-x_2)^2+(y_3+y_2)^2}}{2y_3} \\ \frac{\sqrt{(x_1-x_3)^2+(y_1+y_3)^2}}{2y_1} & \frac{\sqrt{(x_2-x_3)^2+(y_2+y_3)^2}}{2y_2} & 2y_3 \end{bmatrix}$$

$$[P] = \begin{bmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{bmatrix}$$

$$= k * \begin{bmatrix} \ln \frac{b_{11}}{a_{11}} & \ln \frac{b_{12}}{a_{12}} & \ln \frac{b_{13}}{a_{13}} \\ \ln \frac{b_{21}}{a_{21}} & \ln \frac{b_{22}}{a_{22}} & \ln \frac{b_{23}}{a_{23}} \\ \ln \frac{b_{31}}{a_{31}} & \ln \frac{b_{32}}{a_{32}} & \ln \frac{b_{33}}{a_{33}} \end{bmatrix}$$

Where,

$$k : (\text{Constant}) = \frac{1}{2\pi\epsilon_0}$$

$$\epsilon_0 : (\text{Vacuum Permittivity}) = 8.854 \times 10^{-12} \text{ C/V m}$$

$$x : (\text{Horizontal distances of the conductor from the origin}) = [x_1 \ x_2 \ x_3]$$

$$y : (\text{Vertical distances of the conductor from the origin}) = [y_1 \ y_2 \ y_3]$$

$$r : (\text{Radii for the three conductors}) = [r_1 \ r_2 \ r_3]$$

#### **2- Calculating [q] = [P]<sup>-1</sup> \* [v]**

Where,

$$[q] : (\text{Charges at the three conductors}) = [q_1 \ q_2 \ q_3]$$

$$[v] : (\text{Voltages for conductors}) = [v_1 \ v_2 \ v_3]$$

#### **3- Calculating the electric field at a point, then repeat at a range**

For a point M(x<sub>m</sub> , y<sub>m</sub>), the following electric fields in X direction are given as follows:

$$E_{x1} = k * q_1 * (x_m - x_1) * \left[ \frac{1}{(x_m - x_1)^2 + (y_m - y_1)^2} - \frac{1}{(x_m - x_1)^2 + (y_m + y_1)^2} \right]$$

$$E_{x2} = k * q_2 * (x_m - x_2) * \left[ \frac{1}{(x_m - x_2)^2 + (y_m - y_2)^2} - \frac{1}{(x_m - x_2)^2 + (y_m + y_2)^2} \right]$$

$$E_{x3} = k * q_3 * (x_m - x_3) * \left[ \frac{1}{(x_m - x_3)^2 + (y_m - y_3)^2} - \frac{1}{(x_m - x_3)^2 + (y_m + y_3)^2} \right]$$

Then, the total x-coordination of the electric field  $E_x$  is

$$\mathbf{E}_x = \mathbf{E}_{x1} + \mathbf{E}_{x2} + \mathbf{E}_{x3}$$

Similarly, applying the same for y-coordination

$$E_{y1} = k * q_1 * \left[ \frac{(y_m - y_1)}{(x_m - x_1)^2 + (y_m - y_1)^2} - \frac{(y_m + y_1)}{(x_m - x_1)^2 + (y_m + y_1)^2} \right]$$

$$E_{y2} = k * q_2 * \left[ \frac{(y_m - y_2)}{(x_m - x_2)^2 + (y_m - y_2)^2} - \frac{(y_m + y_2)}{(x_m - x_2)^2 + (y_m + y_2)^2} \right]$$

$$E_{y3} = k * q_3 * \left[ \frac{(y_m - y_3)}{(x_m - x_3)^2 + (y_m - y_3)^2} - \frac{(y_m + y_3)}{(x_m - x_3)^2 + (y_m + y_3)^2} \right]$$

Then, the total y-coordination of the electric field  $E_y$  is

$$\mathbf{E}_y = \mathbf{E}_{y1} + \mathbf{E}_{y2} + \mathbf{E}_{y3}$$

Finally, the total electric field  $E_{tot}$  can be calculated as,

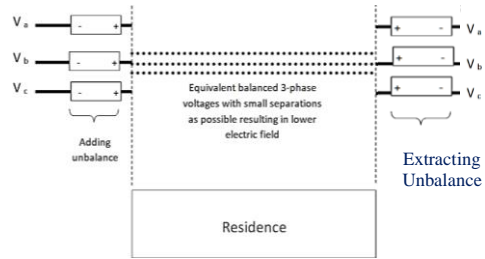
$$E_{tot} = \sqrt{E_x^2 + E_y^2} \quad (9)$$

### III-PROPOSED TECHNIQUE

Fig.3 shows how the voltage unbalances could be used to mitigate the electric field. The negative sequence voltage is inserted in the circuit before the study area and then it is taken out after the end of the study area. It is important to note that the three-phase voltages are balanced before and after the residence, only the part of the transmission line parallel to the residence is unbalanced. The figure illustrates the proposed

method and shows how controlling the voltages is equivalent to changing the positions of the line causing the resultant electric field is minimized.

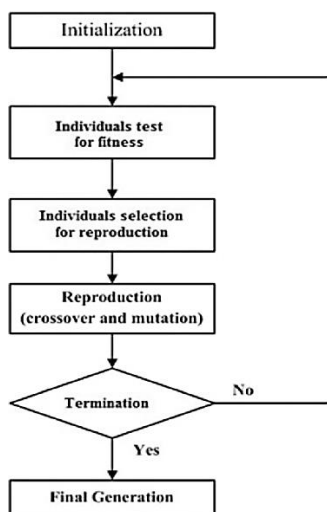
The figure shows also that the voltage unbalance is seen only at the part of line parallel to the residential area however for the overall power system, it is seen as a floating circuit. The voltage unbalance could be inserted using different means such as a voltage source active power filter, series reactive elements, and some special connections of autotransformer [16]. The selection of the suitable method depends on the standard limits of the electric field and economic criterion.



**Fig.3: Graphical illustration of the proposed method**

GA is applied to estimate the values of the negative sequence voltages (three magnitudes and three-phase angles) resulting in minimum electric field mitigation. The standard GA is shown in Fig 4. It is based on the principles of natural genetics and natural selection. The basic elements of natural genetics; reproduction, crossover, and mutation [17, 18]. GA is a heuristic search that reflects the process of natural selection. The fittest individuals are selected for reproduction in order to produce offspring of the next generation. If parents have better fitness, their offspring will be better than parents and have a better chance at surviving. This process keeps on iterating, and at the end, a

generation with the fittest individuals will be found [19, 20].



**Fig.4: GA flow chart**

The genes of the proposed GA are the values of magnitudes and phase angles of the unbalanced voltage inserted into the line at the beginning of the residential area and extracted at the end of it. Voltage magnitudes and phase angles are controlled in the range of 10% the normal values to produce the desired values which result in the best-optimized level of an electric field in the specified residence.

The proposed GA is subjected to the constraint that is the voltage between any two conductors does not exceed the standard limit. The values of voltages magnitudes and phase angles are encoded as binary genes of each chromosome. Fig 5 shows the encoding genes where  $V_m$  represents the rational change in the voltage magnitude and  $V_{ph}$  represents the rational change in the phase angle. The number of genes depends on the number of the line circuits, where each circuit is encoded using six genes.

$V_m$	$V_{ph}$	$V_m$	$V_{ph}$	$V_m$	$V_{ph}$	...	...	$V_m$	$V_{ph}$
1	1	2	2	3	3			n	n

**Fig.5: Encoding of proposed GA**

The fitness function of the proposed GA is the mean value of the electric field induced from the power line over the specified residence area.

**IV-SIMULATION AND RESULTS**

*a. Case study*

The proposed method is applied to an Egyptian medium-voltage single-circuit 11 kV overhead transmission line. The configuration of the 11 kV transmission line and the simulation data are shown in tables 1 and 2.

**Table 1. The configuration of 11 kV transmission line**

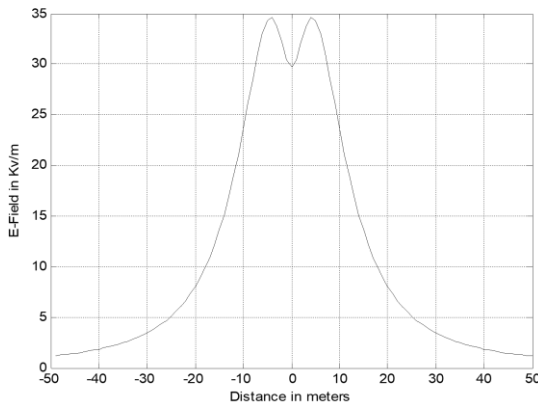
Phase conductor number	Coordinates(m)	
	Lateral distance from the center	Height tower
1	-0.5	10
2	0	10
3	0.5	10

**Table 2. Simulation data of the proposed method**

Voltage magnitude (kV)	Radius of the wires (mm)	The Horizontal range on both sides of the tower (m)	The vertical distance above the ground (m)
11	7	50	2

Fig.6 shows the electric field profile without compensation for the case study described above. The electric field is calculated at medium voltage power line of 11 kV single circuit suspended at towers of 10m high and the lines are separated by 0.5m each.

Fig.6 shows that the peak value of the E-Field is about 35 kV/m, and it occurs at a distance of 5m from the center of the tower. At 10 m from the center of the tower, the E-Field is about 24 kV/m that is greater than the safe value which equals 15 kV/m as stated before.



**Fig.6: E-field Vs distance from the tower at normal case**

**b. Proposed GA**

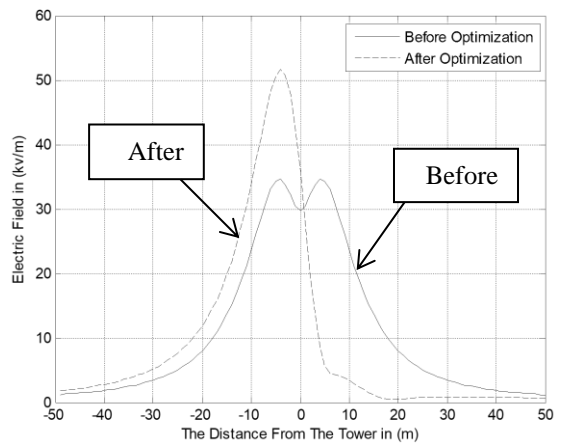
The proposed GA is applied to the case study with the parameters shown in table 3:

**Table 3. GA applied parameters**

Stopping criteria:	The precision of 0.0001 among 30% of the best solutions	Crossover operator:	Two-point
Population size:	100	Probability of crossover:	0.6
Number of genes:	6	Probability of reproduction:	0.3

Selection operator:	Roulette wheel	Probability of Mutation:	0.01
Mutation operator:	Adaptive feasible	Probability of elitism:	0.1

Based on the proposed 6 genes (3 voltage magnitudes and 3 phase angles), the electric field is minimized. Fig.7 shows the electric field profile with and without compensation and the results of the proposed GA are shown in table 4. It is clear that a considerable reduction in the electric field in the residence area. Since the electric field is mitigated on one side of the power line, however on the other side the electric field increases, the proposed method is suitable to residences extending on one side. The peak at the right side is disappeared completely and the E-field at this point (5m from the center of the tower) decreases steadily from 35 kV/m to 5 kV/m. After 5 m there is nearly no field (85% reduction). The main advantage of the proposed method is that the field is decreased continuously to the same level over a range, not a point. However, the main disadvantage of the proposed method is that it implemented on one side.



**Fig.7: The distribution of electric field before and after optimization**

**Table 4. Mean of E-Field before & after GA optimization**

Study case	Voltage magnitudes in (V) and phase angles in (Degree)					The mean of E-Field from 0:50 m at right		The mean of E-Field from 5:50 m at right		
	V <sub>m1</sub>	V <sub>ph1</sub>	V <sub>m2</sub>	V <sub>ph2</sub>	V <sub>m3</sub>	V <sub>ph3</sub>	Field value kV/m	% Reduction	Field value kV/m	% Reduction
Before Optimization	11000	-120	11000	0	11000	120	10.6485	75 %	8.1538	85 %
After Optimization	10670	-116	11850	-6	9906	121	2.6182		1.2318	

*c. The Comparison of the results with other:*

In comparing the values resulting from the proposed method with the values resulting from other effective method, the following results shown in table 5 have been found:

**Table 5. Comparing the proposed method with other**

Evacuation parameters	Proposed Method (inserting negative sequence voltages)	Other effective methods (changing power line geometrical parameters)
Line potential	11 kV	220 kV

Before optimization	8.1538 kV/m	5.0358 kV/m
After optimization	1.2318 kV/m	0.6967 kV/m
% Reduction	85%	86%
Change line construction	No need	mandatory
Optimization cost	Acceptable	High

Where the other effective method is applied to 220 kV power lines. The technique used is to optimize the line geometrical parameters aimed to reduce the intensity of the electric field intensity under an overhead power line. GA and particle swarm optimization (PSO) are used to find the optimum solution [9].

And as shown in table 5 that the mitigation results are too close, but in the proposed method, the cost is low, and don't need any changes in the line construction, as compared to the other method. It is worth noting that the proposed method has been applied to medium voltage while all other researches apply the mitigation techniques to high voltage, in order to make use of the results in Distribution Companies.

**V - CONCLUSION AND FUTURE WORK**

The present paper provides a new technique to mitigate the electric field near the overhead power lines. This technique is based on adjusting the three-phase voltage in the residence zone such that the electric field is minimum. When the desired unbalance voltage is inserted in the power



line, the line conductors will seem like a balanced three-phase voltage located as near as possible to each other resulting in minimum electric field. The negative sequence voltage is inserted into the power line at the beginning of the study area then extracting it at the end of it. GA is used to obtain the desired negative sequence voltages achieving the lowest possible value of the electric field in the study area. The results show high reduction rates of the electric field in the study area. 11 kV medium-voltage line is used as a case study, examining the electric field values before and after mitigation at 2 m height under the power line of 10 m height and 0.5 m spacing between phases and at 50 m long at the right of the tower.

In the future, the optimized genes; the voltages magnitudes and phases of the three-phase line; could be replaced by their corresponding series reactive elements that cause the desired voltage to unbalance assuming constant line current.

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## التخفيف من المجال الكهربائي بالقرب من خطوط الطاقة باستخدام فرق الجهد السلبي

طبقاً لما ينص عليه قانون حماية المنشآت الكهربائية، فإنه من غير المسموح به توصيل التغذية الكهربائية لأى منشأة تقع في حرم أو تحت خطوط القوى الكهربائية. ولكن واقع الأمر أن شركة توزيع الكهرباء تكتشف يوميا العديد من المخالفات، والتي يتم تغذيتها من خلال الشرطة، ولسوء الحظ يتوقف الأمر في غالب الأحيان عند حدود الإكتشاف.

هذه الحالات لا تزال تعيش بالقرب من خطوط القوى، مع ما هو معروف من خطورة المجالات الكهربائية الناتجة عنها، وهناك دلائل قوية أن هذه المجالات قد تسبب السرطان فضلا عن العديد من الأعراض الأخرى والتي يمكن للإنسان ملاحظتها مباشرة مثل: ضعف الذاكرة، الإرهاق المزمن، الإكتئاب، الغثيان، والطفح الجلدي. وبالتالي فمن الضروري البحث عن طريقة لحماية هذه الفئات. قد تكون التقنيات التقليدية للتخفيف من هذه المجالات فعالة في المناطق ذات المساحات الشاسعة، إلا أنه في المناطق ذات الكثافات السكانية الكبيرة، يجب تقديم تقنيات أخرى.

### إطار البحث:

الفكرة المقترحة تعتمد على أن المجال الكهربائي الناتج عن الجهود ثلاثية الطور يقل كلما قلت المسافة بين الخطوط الثلاثة (كما ينص على ذلك قانون كولوم)، وهو الأمر الذي لا يمكن تحقيقه في حالة خطوط القوى الكهربائية. ولكن من الممكن التوصل لحالة مماثلة عن طريق التحكم في الجهود ثلاثية الطور لتبدو كما لو كانت المسافات بين الخطوط صغيرة جداً، من خلال خلق عدم اتزان في الجهد بين الخطوط الثلاثة في بداية المنطقة السكنية ثم التخلص منه في نهايتها.

تستخدم الخوارزميات الجينية للحصول على التصميم المطلوب، والذي من خلاله يصبح المجال الكهربائي الناتج أقل ما يمكن. الخوارزميات الجينية هي أحد التقنيات الهامة في البحث عن الخيار الأمثل من مجموعة حلول متوفرة لتصميم معين.