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Optimal Location of Surge Arresters in Distribution Network Considering Reliability and Technical and Economic Factors to Reduce Costs using ICA Algorithm

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Abstract

Due to increased energy consumption in cities and industrial areas, many technical and economic issues arise for designers and beneficiaries of the system. Currently, unfortunately, in choosing the right place for installing arrester, the traditional methods are used and without considering the economic issues and the reliability of the arresters, they are used and this equipment is installed and putted into operation on this basis. In this paper, an intelligent optimization method called the Imperialist Competitive Algorithm (ICA) is proposed to select the appropriate protection plan. Considering the combined economic and technical factors, the location of the lightening arrester is determined in a distribution network with the aim of reducing risk Insulation. The proposed method has been implemented on one of the long feeders of Mazandaran Electricity Distribution Network, which results in identifying the efficiency of the proposed algorithm in comparison with traditional methods in the optimal location of the arrester.

Keywords: Distribution networks, optimal location, surge arrester, insulation risk, lightning waves, Discrete imperialist competitive algorithm (DICA)
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1. Introduction

Every year, the total non-distributed energy in the distribution grid of the country's power supply (in terms of megawatts) is very significant compared to the global standards. The magnitude of the damage caused by unsupplied energy in terms of the rial equivalent imposed on both sides of the supply and consumption of electricity will increase the need for scientific solutions and measures to reduce the stagnation and outage. The benefits of reducing power outages, while beneficial to the economy and industry, will also be beneficial in promoting the national economy and taking advantage of the economic opportunities arising from the non-stop of the huge energy cycle. According to the IEC standard [1], over voltages of lightning are more important in the voltage stresses in the distribution network. To prevent the risk of excessive lightning strikes, protective devices such as arresters are used [2]. Given the fact that there is no need to completely eliminate all stresses due to lightning due to investment restrictions, choosing the optimal location for arresters to improve network performance is important.

One of the important researches in the field of optimal location of the arrester is the determination of their optimal location on the power grid based on technical issues, while the considerations of lightning stresses are ignored only in economic analyzes. [3-5]

Lightning stresses are only noticeable in a few spins adjacent to the point of impact and do not affect other parts of the network. Therefore, the insulation risk of any point should be checked according to the lightning stresses in the vicinity of the same point and in a discrete manner. Therefore, the method presented in [3], which examines the problem in continuous space, is not suitable for large networks.

In this paper, a method based on statistical analysis of lightning waves is proposed to select the appropriate protection scheme for a distribution network, which, taking into account the combined technical and economic factors, determines the optimal location of the arresters in the grid, taking into account a specific insulating risk value. To implement the proposed method, the first is a statistic based on the IEEE 1410 standard is introduced to investigate the lightning strike effects of direct and indirect lightning strikes in the distribution network and then, using its results and with the help of a new probabilistic form, the network instability risk is calculated. Finally, using an optimal method based on the discrete imperialist competitive algorithm DICA, with the aim of reducing the insulating risk of the optimal site of the arresters, is determined. [4-6]

2. Determining the point of lightning strike

A) The area of lightning strike to the ground

The main parameters for the definition of the lightning wave are the peak of the amplitude of the current I_p, the peak time T_r, and the time behind the wave T_t in the study of overvoltages. The data collected from various experiments has shown that the statistical behavior of each of the lightning variables can be approximated by a normal logarithmic function, which shows the mean logarithmic values of L_{nx} and the variation of the normal logarithmic distribution of lightning parameters in [7].

The location of the lightning strike during the span is determined using a striking surface as shown in Fig. 1. The length of this region is equal to the length of the span and its width is equal to (d), which is determined by the maximum range of the lightning current [8-10]. In other words, for each lightning current, the point of striking with the coordinates (x, y) is generated with a uniform distribution, so that the component x changes from 0 to the length of the span and the component y varies between ± d/2.

B) The final point of strike

Lightning strikes can be applied to the guard wire, phase conductor, or earth adjacent distribution lines; to determine the final point of strike, the EGM model (Fig. 2) has been used. [7] In this model, the strike distances are obtained from the following relationships[11]:

$$R_g = 0.9R_c \quad R_c = 10\, I_P^{0.65} \tag{1}$$

Therefore, for each I_P lightning current, the strike distances to phase conductor, R_c and guard wire, R_g can be calculated and obtained an EGM model.

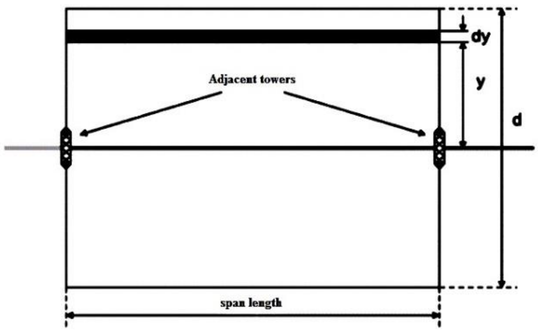

Fig. 1. The surface of the lightning strike to the ground [12]

With respect to Fig. 2, the distances D_g and D_c are the distances to the phase conductor and guard wire, respectively. Y_{min} is the minimum distance in the vicinity of the line that the lightning strike does not diviate to the line. If the lightning strike strikes around the distribution lines, it is possible to induce more voltage than the insulation resistance of the grid in the line: Y_{max} is equal to the maximum distance that the inductive overvoltage caused by the striking of each lightning current does not lead to electric discharge.

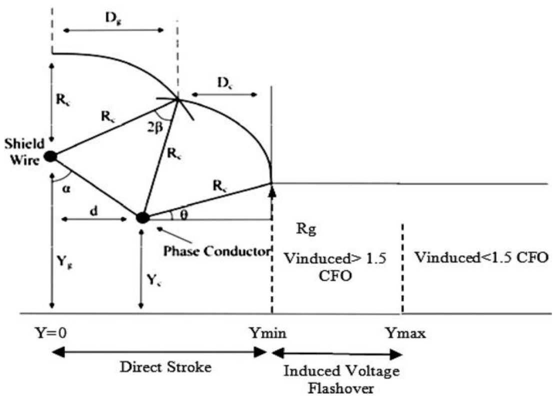

Fig. 2. The line Electrogeometrical Model (EGM) [13]

The above distances are calculated from the following relationships: [13]

$$D_c = R_c[cos\theta - \cos(\alpha + \beta)] \tag{2}$$

$$D_g = R_c \cos(\alpha - \beta) \tag{3}$$

$$\beta = sin^{-1}\frac{(Y_g - Y_c)\sqrt{1 + tan^2\alpha}}{2R_C} \tag{4}$$

$$\theta = sin^{-1}\frac{Y_g - Y_c}{R_C}, \propto = tan^{-1}\frac{d}{Y_g - Y_c} \tag{5}$$

$$y_{min} = \sqrt{R_c^2 - (R_g - Y_C)^2} \tag{6}$$

If the vertical lightning wave approaches the line at Dc, it hits the conductor wire and creates a security failure (SF), and if enter from the space Dg, it ends with the guard wire and causes the back flash over (BF) and if Encountering the earth at a distance between Ymax to Ymin creates an induction overvoltage in the phase conductor and discharge due to induced flashovers (IF). In this thesis, the under study distribution network does not have a guard wire, and as a result, technical studies are not provided.

3. Over-voltages in the distribution network

After determining the location of the lightning strikes using the EGM model, the resulting voltages are calculated from the following relationships [7-15].

A) Lightning Striking to phase conductor

In the case of a direct lightning strike with an Ip current to a phase conductor, the maximum resulting voltage is equal to [2]:

$$V = Z_c.\frac{I_P}{2} \tag{7}$$

Where Z_c is the phase conductor wave impedance. If the Utility pole is equipped with a lightning arrester and the lightning strike to the span between the two poles with an arrester and the other without an arrester, the voltage on the Utility pole that is not equipped with arrester is equal to [16]:

$$V = V_{IR}.\frac{L}{2}.\frac{Z_c I_p}{T_r c} \tag{8}$$

Where VIR is the discharge voltage of the arrester, L is the length of the span, c is the speed of light $(3 \times 10^8\, m/s)$ and T_r is The peak time of the returning shock wave.

B) Lightning strike on the ground

Because of the low height of the distribution network lines and the presence of buildings and trees around the lines, most lightning strikes hit the ground around the lines. In this case, the voltage induced by the lightning strike I_P to the ground is calculated from the following equation [16]:

$$V_{max} = \frac{Z.I_P h}{y}\left(1 + \frac{1}{\sqrt{2}}\frac{v}{c}\frac{1}{\sqrt{1-0.5\,.\,(v/c)^2}}\right) \tag{9}$$

Where y is the closest distance between the strike and line, h is the mean conductor height, v is the returning strike speed $(1.2 \times 10^8\, m/s)$ and zo is the wave impedance.

If the lightning wave strike vertically to the ground around the non-arrested utility pole, the voltage applied to this utility pole will be below [16]:

$$V = V_{IR} + \frac{2LV_{pk}}{T_r c} \tag{10}$$

Where L and C, V_{IR} are defined in the foregoing relations, and V_{Pk} / T_r is the inductive voltage increase rate.

4. Calculating the insulating risk caused by the lightning

A) Insulating risk at any point in the network

The risk of failure of any equipment due to lightning is defined as the exceeding of probability of the lightning stresses from the insulation resistance of the equipment. In order to determine the insulating risk function of the equipment at any point in the network, the overvoltage density of the lightning strikes and the distribution function of the insulation strength with the assumption of normal distribution for the desired equipment must be specified [17-18]. Assuming a normal distribution for the above functions, we can propose the probabilistic form of the risk integral for distribution networks as follows:

$$R_{Ins} = \int_0^{v_1} f_{ph}\,(V).P(V)dV + \int_0^{v_{max}} f_g\,(V).P(V)dV + \int_0^{v_{ind}} f_{ind}\,(V).P(V)dV \tag{11}$$

Where P (V) is electrical discharge probability, fg (v), fph (v) and find (v) is the function of the superconducting probability density of SF, IF and BF, respectively. Vl, Vmax and Vind are the maximum stored voltages generated by IF, BF, and SF, respectively.

B) The overall insulation risk of the network

To determine the overall risk of the network, weighted risk is used, so that they are assigned different values according to the importance of protecting the different points of the network. In this case, the risk weighted of the network, R_G, is defined according to the technical and economic considerations as follows:

$$R_G = \frac{1}{\sum_{i=1}^{n} T_i S_i E_i}\,.\sum_{i=1}^{n} T_i S_i E_i \times R_{Ins} \tag{12}$$

RIns (i) is the risk value in the i-th node, which is computed from equation (11) and n is the number of utility poles in the network. T_i, S_i and E_i are a technical, abundant and economic indicator, respectively. Subsequently, the essential aspects of these indices are defined.

C) Risk of arrester failure

Limiting the installation of arresters in a distribution network may result in an additional outage because of failure increasing due to the lightning that is calculated by the risk of the arrester failure.

$$R_{Arr} = \int f(E).F_W(E)dE \tag{13}$$

Where f (E) is the probability density probability of energy stress, F_W (E) is the energy absorption power of the inhibitor given by the cumulative distribution. [6]

$$F_W(E) = 1 - 0.5^{((E/E_R - 2.5)/1.5+1)^5} \quad (14)$$

– *Technical Indicator, Ti*

This index specifies the importance of each node for protection based on the distance from the substation. By increasing the distance from the substation, the entrance waves to the substation are weakened, so the points that are adjacent to substations or branching points are more important in terms of protection.

– *Frequency indicators, Si*

This index specifies the importance of each node for protection based on the distance from the substation. By increasing the distance from the substation, the entrance waves to the substation are weakened, so the points that are adjacent to substations or branching points are more important in terms of protection.

$$s_i = \left| \frac{LFOR_{span}(i-1) + LFOR_{span}(i)}{2\sum_{i=1}^{n} \frac{LFOR_{span}(i)}{n}} \right| . K_{ait}(i) \quad (15)$$

Where $K_{ait}(i) = 1/5^{((Altitude(i) Average\ Altitude)-1)}$ and $LFOR_{span}(i)$ is the number of electrical discharges due to lightning strikes in ith Span, calculated by the Monte Carlo simulation method, n is the number of utility poles in the network and K_{ait} is a coefficient representing the effect of the height on the lightning strike occurrence rate in each of utility poles [19].

– *Economic Indicator, Ei*

According to the maximum annual outage cost in the power distribution network that is due to the outage in the i^{th} utility pole, $C_{T\ max}$, the corresponding weight of each pole, is calculated as follows:

$$E_i = \frac{C_T(i)}{C_{T\,max}} \quad (16)$$

Where CTi is the annual cost of the distribution network due to the installation cost of the equipments and the outage in the i^{th} utility pole [20].

$$C_T(i) = C_i(i) + C_m(i) + C_o(i) \quad (17)$$

Where the CI ($ / 100km, year) is the annual cost of the investment in the protective equipment used in the i^{th} utility pole, CM ($ / 100km, year) is the annual cost of maintenance of the protective equipment equal to 0.20 annual cost of investment, CO ($ / 100 km, year) is the annual cost of the line outage due to the outage in the i^{th} utility pole and the annual cost of the investment is as follows [20]:

$$C_I = \frac{I_R\,(I_R+1)^Y}{(I_R+1)^Y - 1}\, C_n \quad (18)$$

Which I_R is interest rate, and Y is the operating time per year, and CTI ($ / 100 km) is the total investment cost.

The definite cost includes two separate sections. The first part of these costs relates to the definite cost of the line for the district electricity company, and the other major part is related to the definite cost of the consumer. The second part is especially important for distribution lines that are facing many consumers [21]. The average annual cost of the line outage for consumers can be expressed as follows:

$$C_o = \text{LFOR}_{(i)} \times P_o(C_{NPC} + C_{NEC}.t_i) \quad (19)$$

Where $\text{LFOR}_{(i)}$ is the annual number of lightning strikes in the i^{th} utility pole, P_o(kW) is outage power due to the line outage, C_{NPC}($/kW) is the average annual cost of non-delivered power to consumers , C_{NEC} ($ / kWh) is the average annual cost of energy not delivered to consumers and t_i (h) is the mean of line failure time.

5. Optimization method

A) Imperialist Competitive Algorithm

as colonizers. The rest of the population is also It is a new algorithm for evolutionary computing, which, like other evolutionary algorithms, begins with a number of random primitive populations, each of which is called a country [22]. Some of the best elements of the population are chosen considered to be a colony, which together form empires. Colonialists, depending on their power, attract these colonies, which at this stage, the colony may become stronger than colonialist by the policy of absorbing and takes its place. With the formation of primitive empires, imperialist rivalry begins between them, so that each Empire, depending to its power, tries to absorb the colonies of competing empires. Any empire that fails to succeed in colonial competition and adds to its power will be eliminated from the colonial competition, which will eventually be an empire that the colonizer and colony will have the same cost. In the following, the basic aspects of the ICA are briefly outlined.

B) Formation of primitive empires

In a N-dimensional optimization problem, each country is an array of [1 × N] (Country=[P1,P2,…,Pn]) that each country's cost is determined by evaluating the objective function F.

$$Cost = F(Country) = F\,([\,p_1, p_2, \ldots, p_3] \quad (20)$$

To start the algorithm, we create N primary countries. N_{imp} are selected from the best members of this population (countries with the least amount of cost function) as colonial countries. The remaining of nations (N_{col}) form colonies, each of which belongs to an empire. To distribute the initial colonies among colonizers in proportion to their strength, we calculate the normalized cost:

$$C_n = \max\{C_i\} - c_n \quad (21)$$

Where c_n is the cost of n^{th} colonizer and C_n is the normalized cost. With the cost of colonizers normalization, the relative power of each colonizer is calculated as follows, and according to this, the colonial countries are divided among them.

$$P_n = \left|\frac{C_n}{\sum_{i=1}^{N_{imp}} C_i}\right| \quad (22)$$

Therefore, the initial number of colonies of each colonizer will be equal to:

$$NC_n = rand\{p_n \times N_{col}\} \quad (23)$$

Where NC_n is the initial number of colonies of the n^{th} empire and N_{col} is also the total number of colonial countries.

C) Absorption policy

The colonial countries, by applying the policy of absorbing (assimilating) towards the various axis of optimization, take colonial countries. (Fig. 3) shows the general scheme of this move.

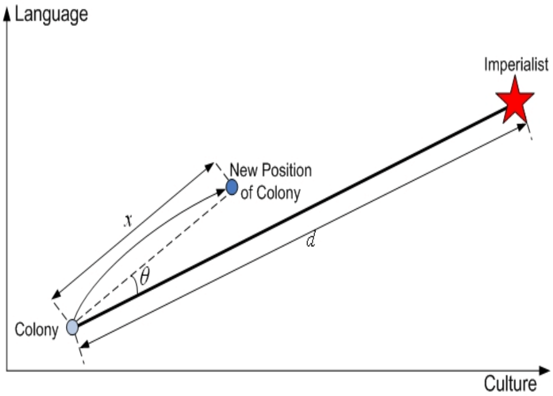

Fig. 3. Moving the colonies towards the colonialist [23]

In this movement, θ and x are random values with uniform distribution that are calculated using the following relationships:

$$x \sim U(o, \beta \times d), \quad \theta \sim U(-\gamma, \gamma) \quad (24)$$

Where d is the distance between the colonizer and the colony, (*β=2*) is a coefficient that causes the colony country to approach the colonialist country from various directions, and (γ =45 °) is a parameter that determines the degree of deviation of the colony country from the connector vector.

D) Revolution of the colony

The revolution is modeled by the random movement of a colony country to a new random position. From an algorithmic point of view, the revolution will save the entire evolutionary movement from being stuck at the local optimum points, which in some cases improves the position of a country and brings it into a better optimal area.

E) The whole power of an empire

The power of an empire is equal to the total power of the colonialist country and a percentage of the power of its colonies as defined below:

$$TC_n = Cost(imperialist\ _n) + \xi\, mean\{Cost(colonies\ of\ empire\ _n)\} \quad (25)$$

Which TC_n is the total cost of the empire n and ξ is a positive number that is usually considered to be less than one [24].

F) Colonial competition

All empires are trying to capture the colonies of competing empires and to dominate them. During this competition, the weak empires lost their colonies and the stronger empires captured these colonies and added to their power. To model this colonial competition, first, the probability of seizing colonies by each empire is calculated as follows:

$$NTC_n = \max\{TC_i\} - TC_n \quad (26)$$

Which NTC_n is the normalized total cost of the n^{th} empire and TC_n is the total cost of that empire. The probability of seizing each empire is calculated as follows.

$$P_n = \left|NTC_n / \sum_{i=1}^{N_{imp}} NTC_i\right| \quad (27)$$

Knowing the probability of seizing each empire, a mechanism like the roulette cycle of the genetic algorithm is needed to give the competed colony to one of them with the probability that it proportional to the power of the empires.

After all, all the weak empires will eliminate and we will have only one empire, and the rest of the colonial countries will be controlled by this single empire that the positions and costs of colony countries are equal to the position and cost of the colonialist country.

6. Discrete imperialist competitive algorithm (DICA) and Object function

In general, the colonial competition algorithm has a continuous nature, but with some modifications, this algorithm can be used to solve problems in a discrete space. Given that lightning stresses are only noticeable in the adjacent area of the point of strike and do not affect other parts of the network, the study is assumed as a discrete problem.

Therefore, in the lightning study, the discrete imperialist competitive algorithm has been used due to its emergence and proper function in the convergence rate and overall optimal achievement. First, you need to binary coding for the problem. Therefore, the number of bits in each country is equal to the number of points for the deployment of the arrester in the distribution network. Then, in the presence or absence of the arrester in the utility pole, the value of each bit in the country is equal to one or zero, respectively.

Colonialist countries are trying to attract colonies to their own and to model this displacement, a number of colony arrays bits must be changed. Therefore, 40% of the bits of the colonialist array are selected and replace the corresponding bits in the colony array [24]. In Table 1, the structure of the transferred colony array is similar to the colonialist array.

Table.1.
Modification of the colony displacement toward the colonialist [23]

Imperialist	***1***	***0***	***0***	***1***	***0***	***1***	***0***	***1***	***0***
Colony	0	1	1	1	1	0	0	0	1
Shifted colony	1	0	1	1	0	0	0	1	0

According to that, the number of arresters used in the problem is constant, the number of one in the array of countries must be equal to the number of arresters, and otherwise a mandatory jump will be applied to the colony array to maintain the number of single ones.

The object function in the proposed method is to minimize the creation of risk in the network and LFR errors by determining the optimal location of a specific number of arrester. In addition, due to the existence of the arrester breakdown rate, the object function is defined as follows:

$$Min\ F = \left[\frac{1}{\sum_{i-1}^{n} T_i S_i E_i} \times \sum_{i-1}^{n} T_i S_i E_i \times \left(R_{Ins}(i) + R_{Arr}(i)\right)\right] \quad (28)$$

Where $R_{Ins}(i)$, $R_{Arr}(i)$, T_i, S_i, E_i and n are expressed in the foregoing relationships.

$R_{Ins}(i)$ is the risk of failure of each equipment due to the lightning strike and is determined by the exceeding of probability of lightning stress from the insulation strength of the equipment.

$R_{Arr}(i)$ is the risk of arrester failure and limiting the installation of arresters in the distribution network may result in an additional outage due to a failure due to increased lightning.

T_i specifies the importance of each node for protection based on the distance from the substation. By increasing the distance from the substation, the entrance waves to the substation are weakened, so the points that are adjacent to substations or branching points are more important than other points in terms of protection.

Si specifies the importance of each node for protection based on the distance from the substation. By increasing the distance from the substation, the entrance waves to the substation are weakened, so the points that are adjacent to substations or branching points are more important than other points in terms of protection.

E_i is a coefficient arising from the maximum annual power outage in the distribution network, which is due to the i^{th} utility pole outage.

7. Introducing the sample network

Figure 4 shows a single-line diagram of a grid of one of the 20 kv feeders located in the south of Sari. The network has a length of 13.322 km and has 277 bases and is important for lightning studies.

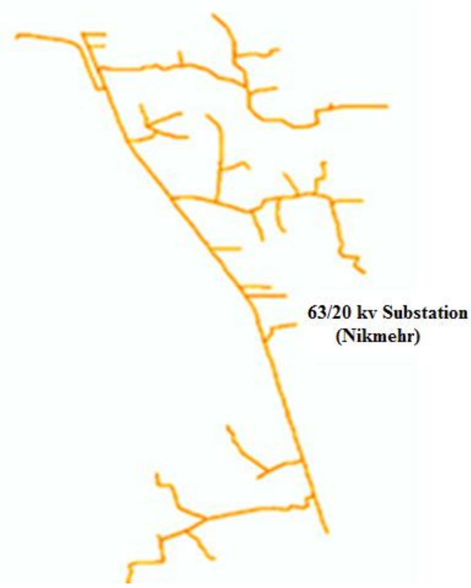

Fig. 4. Arrangement of the studied feeder distribution network

The specifications of the network and the conductor used are shown in table 2.

Table.2.
Specifications of the equipment's studied network

Conductor	***Hyena***
Basic Insulation Level (BIL)	150 Kv
Network Length	13/322 Km

In this paper, the Monte Carlo method is implemented on each of the network points 100000 times, so that each set of generated random parameters is applied to the network and the resulting over-voltages are determined using MATLAB software and the arrester energy stresses are calculated using the established relationships and finally by calculating the mean value and standard deviation in each utility pole and forming the stress and strength distribution functions, insulation risk and lightning flashover rate (LFOR) are calculated.

Table.3.
Selective Surge Artist Specifications

Nominal discharge current (kA)	***10***
Nominal Voltage (kV)	25
Permanent working voltage	20
Price of each three-phase set (Rial)	5750000

According to the investment cost set by the power company for the protection of the studied network, there are 40 arresters on the grid, the specifications of which are shown in table 3.

8. Lightning wave modeling

Given the random nature of the lightning waves and the relationships expressed in the previous chapter, using a Monte Carlo method on each of the network points, a set of random parameters related to the lightning wave is generated. As shown in table 4, the lightning wave has two random parameters of the climb time (Tr) and peak flow (ip), both of which follow the logarithmic probability distribution function according to the table 4.

Table.4.
Statistical parameters of shocks of negative feedback [10]

Parameter	***ln x***	***Σ***
Ip	10 kA	0.48 kA
Tr	8 μs	0.55 μs
Tt	20 μs	0.58 μs

The parameters (Tr) and (Ip) were repeated 100,000 times randomly using the Monte Carlo method and were produced to achieve the desired convergence.

Figure 5 shows the convergence process of the Monte Carlo method for generating peak current values for 2000 repetitions. To illustrate the accuracy of the Monte Carlo method in modeling the random behavior of the lightning wave, the distribution function of 100000 parameters (Tr) and (Ip) is shown in figure 6. As it is clear, the distribution function is consistent with the parameters of the lightning wave information of table 4 after 100,000 repeats, which represents the logarithmic normal distribution function.

After generating the parameters (Tr and Ip) with the Monte Carlo method, the resulting overvoltages were obtained using the established relationships, and finally, by calculating the mean values and standard deviations in each base and forming the stress distribution and insulation strength functions, The overall insulation risk is calculated from the base to the base. Figure 7 shows the cumulative distribution function of one of the bases.

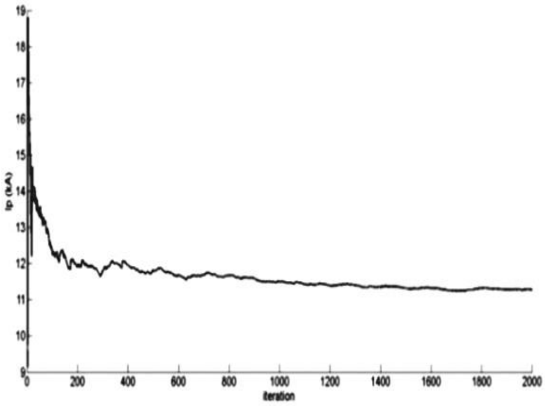

Fig. 5. Convergence trend of the Monte Carlo method

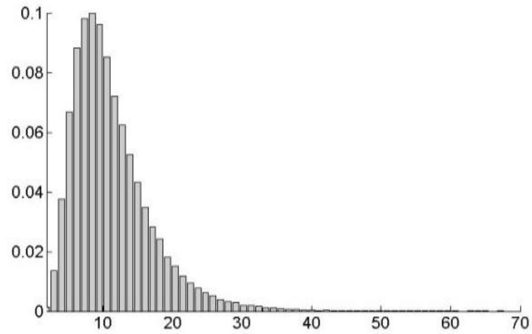
Fig. 6. Lightning wave distribution function

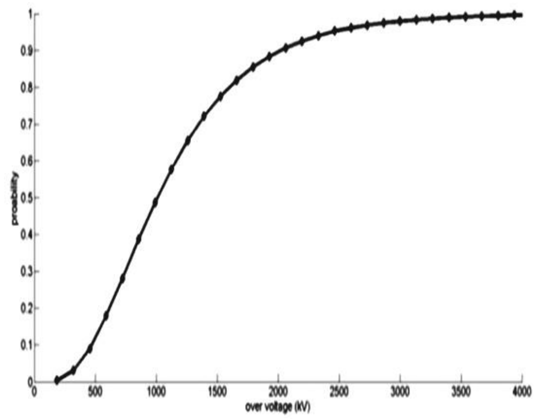

Fig. 7. Cumulative distribution function for one of the bases

9. Simulation and numerical conclusion

To illustrate the efficiency of the proposed algorithm compared to the traditional methods available for the optimal location of the arrester, simulations and numerical conclusions are made in the following two sections:

A) Comparison network without protection, protection with arrester, protection with optimal arrester

In this section, the amount of overvoltage and insulating risk of the grid in a non-arrester mode, 40 existing arrester on the network and finally with an optimal location of 40 arresters are compared. In order to optimize the location of arrester by the Monte Carlo method from the calculation of the values of lightning waves, the optimal location for the arrester is determined using the imperialist competitive algorithm, and then the resulting overvoltage is calculated from this location. This process continued with the convergence of the imperialist competitive algorithm to calculate the optimal location for 40 arresters. Figure 8 shows the convergence diagram of the imperialist competitive method.

As is clear from the above, the imperialist competitive algorithm is consistently reducing the amount of the object function (overall network insulating risk), and this decreasing trend continues to reach the maximum number of repetitions. After reaching the convergence of the imperialist competitive algorithm and calculating the optimal locations of the arrester, the comparison table 5 for the overvoltage of the lightning strike to the SF phase conductor and the lightning strike to ground adjacent IF is provided. It is clear from table 5 that the maximum instantaneous overvoltage due to strike of the lightning wave to phase (SF) in an unprotected network is approximately equal to 2 times the network with an existing arrester and 4.6 times the network with an optimal location. Compared to existing surge arrester and optimal arrester, given that the number of arresters in both cases is equal to 40, it is clear that with the optimal location of the arrester on the network (not necessarily on all transmissions), the amount of overvoltage can be reduced to about 5 / 2 times reduced. Also, the standard deviation in the optimal location of arrester is much lower than that of the existing surge arrester, indicating that the overvoltage is more uniform on the grid with the optimal surge arrester, that is, the protection is properly distributed throughout the grid, rather than in Some areas have excellent protection and in some areas without protection.

With reference to Fig. 9, it can be noted that due to the fact that it's not required to install the arrester at all points and transformer nodes of the network, the allocation of new arresters is removed from the unnecessary points and are introduced in the process based on the optimal location of the new points, that this optimum locations results in a more reliable network and provides the correct protection function that is cost effective for the power distribution company. The installation location of 40 existing arrester and arresters calculated from the imperialist competitive algorithm is presented in Table 6.

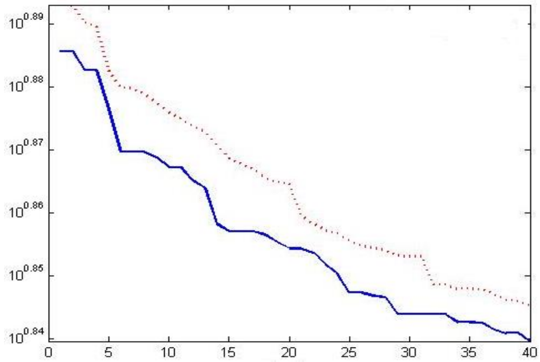

Fig. 8. Convergence of imperialist competitive method

Table.5.
Overvoltage caused by lightning

Network protection type	Case	Overvoltage value Maximum	Minimum	Standard deviation
No protection	SF	13774	1326.8	701.45
	IF	198.18	20.24	10.35
with surge arrester	SF	6925.5	595.64	411.26
	IF	198.18	20.24	10.35
with optimal surge arrester	SF	2950	222.84	120.36
	IF	116.58	20.24	10.31

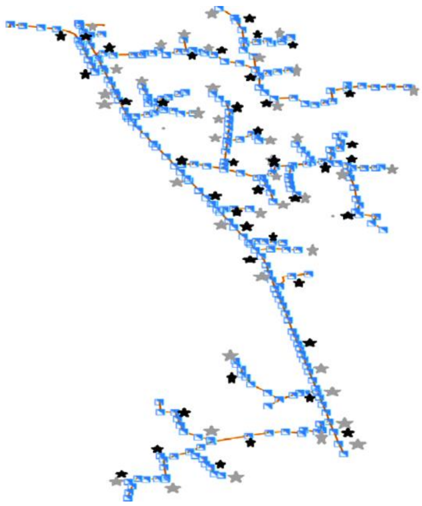
Fig. 9. Positioning the existing surge arrester and optimal arrester

Table.6.
Comparing the results of different optimization methods

Case	Installation location of surge arrester
Existing surge arrester	6,14,21,33,35,38,50,54,58,60,73,75,83,91,95,111,114,121,129,137,152,155,159,163,168,174,178,187,195,200,212,219,228,240,243,244,251,256,258,263

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Optimal surge arrester	2,8,13,18,33,46,59,62,70,81,87,94,103,109, 117,120,122,129,133,136,143,147,157,162, 166,174,182,191,208,216,219,224,228,235, 250,252,256,261,267,274

The significant difference between the total insulation risk of the grid in the non-arrestor and arrestor mode is fully described in Fig. 10, and this shows the effect of the presence of a arrester in the grid, either optimally or in a non-optimal manner. The total insulation risk of the entire network with an existing arrester is 7.7, and after the location of the arrester and the optimum location of the installation, this insulating risk is reduced to 6.04, which resulted in a 57% reduction in the maximum network overvoltage. In order to better investigate the effect of optimal location of the arrester, the insulation risk diagram and the maximum overvoltage in three modes without a surge arrester, with an existing surge arrester and an optimal surge arrester are given below.

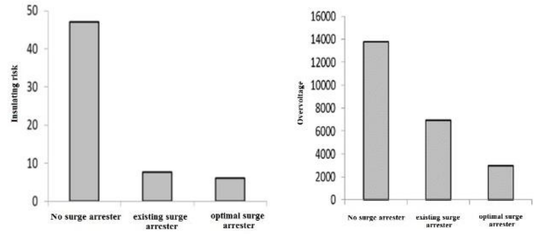

Fig. 10. Insulating risk (a) and maximum overvoltage (b) diagram in three modes: without surge arrester, with existing surge arrester and optimal surge arrester.

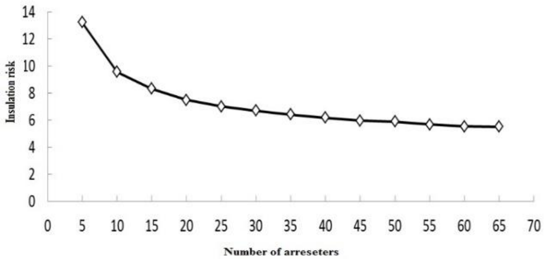

Fig. 11. Total network insulating risk variation curve

B) Analysis of the sensitivity of insulating risk changes to arrester changes

In this section, sensitivity analysis has been used to investigate the effect of the arrester on the overall insulation risk of the network and as a result, determining the optimal location of the needed arrester to reach the acceptable risk level, so that We have changed the number of arresters from zero to 65 (5 arrester in each step) and at each stage, using the imperialist competitive algorithm, the optimal location for the arrester has been obtained, and then the amount of overvoltages and the overall insulation risk of the network is calculated. The diagram below shows the total insulating risk variation curve of the network relative to the changes in the number of optimal surge arresters. Figure 11 shows the variation of insulation risk based on changes in the number of arrester (with the optimal location of the arrester). Based on this curve, the operator can determine the number of optimal surge arrester to achieve the desired insulation risk. For example, to achieve an insulating risk of less than 8%, it is necessary to install about 18 arresters in the network.

The remarkable thing to note in figure 11 is that it is only necessary to install the 20 surge arresters in an optimal manner in the network to achieve the existing insulation risk with the existing surge arrester (about 7.7% with 40 available spark plugs in a non-optimal manner). This means that by installing 20 arresters optimally with the proposed algorithm, the risk of insulation can be 7/7 percent. As a result, reducing the number of existing surge arrester to (20) can prevent additional charges on the network.

By installing a small number of arresters, the insulation risk changes are very high and are at high rate. However, with the increase in the number of arresters on the network, these changes have fallen sharply, so that if the number of arresters exceeds 40, there will be no decrease in the insulation risk of the network, which means that installing the surge arrester for more than this amount does not improve the protection of the network and will only charge additional costs to the user.

The reason for not changing the insulation risk when installing many arresters is that by increasing the installation of the arrester on the network, there is a possibility of interference in the operation radius of the arresters, so that by installing an additional surge arrester, the arrester is placed in the operation radius of the other arresters and has no effect on the network protection. According to the above, installing insufficient and low results in significant changes in the insulation risk and is not cost-effective, and over-mounting the surge arrester will not change the overall insulation risk of the entire network and will only impose additional costs on distribution companies.

10. Conclusion

The main objective of this paper is to increase the accuracy of the analytical methods available to calculate the performance of the distribution network against lightning using the Monte Carlo method and the optimization algorithm. An optimization method based on discrete imperialist competitive algorithm (DICA) determines the optimal location of the arresters with the aim of reducing the insulating risk of network. In the proposed method, a new probabilistic form to calculate the insulating risk and a function for the economic weight of the candidate points is proposed that considers the importance of different network equipment as well as the flow of different power values in different network lines. The results confirm the better performance of the proposed method in comparison with traditional methods in determining the optimal location of arresters from both economic and technical point of view so that the annual cost is reduced with regard to the cost of equipment and the cost of the outage.

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