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Electrical Distribution System Reliability Improvement by Optimal Placement of Fault Indicators using Immune Algorithm

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ABSTRACT
This paper proposes a methodology for optimal placement of fault indicators in distribution networks. The main objective is reliability improvement with consideration of economic aspects. Thus, it is defined as a minimization problem to minimize the Total Cost of Reliability (TCR). TCR is considered as the sum of customer interruption cost and the investment cost on fault indicators. The Artificial Immune Algorithm (AIA) is adopted to solve the proposed problem efficiently. The performance of the proposed approach is assessed and illustrated by studies on the real Iranian distribution network.
Keywords - **Fault indicator, artificial immune algorithm, distribution automation systems.**

1. INTRODUCTION
It is necessary for the distribution utility to supply the electricity with acceptable degree of power quality for customers. Statistical studies indicate that due to radial structure of feeders and high failure rates in equipment, major number of faults occurs in the distribution networks. Fault detection is one of the important processes in network management for the guarantee of its security. During the past years, a few scenarios have been used in fault locating [1-4].
In general, there are two methods for improving the reliability of distribution networks. The first method is to reduce the frequency of interruption and the second is to reduce the outage duration while fault occurs. Installation of FIs in the primary feeders of distribution network is one of way to decrease the outage duration. In [5] the effect of FIs are surveyed on the reliability index of distribution network, and after describing the model and the required methods for reliability assessment of distribution network with installation of FIs, a proposed model has been used on a real network in Iran with considering a fixed place for FIs. In [6] optimal placement of FIs, has been used in order to improve the reliability and supplied power quality to the customers with application of fuzzy logic. In [7] different methods of fault detection in distribution and transmission networks has been surveyed and the advantages and disadvantages of each methods in the detection of fault has been compared with each other. In [8] the effect of fault indicators placement, with using the genetic algorithm, has been surveyed on energy not supplied and the interruption cost. In [9] the optimal placement of fault indicators is studied with using the artificial immune algorithm, and with the vaccine injection in immune algorithm, total cost of reliability has been assessed with regard the key customers.
The FIs are designed in a way that have been installed in various points of the network, and it indicate if the short circuit current has been passed through placing of set or not? In the other hand, they have point information. The FIs can be used with and also without distribution automation system. If they do not equipped with telecommunication systems for sending signals, when fault occur in network, all of sets that have been installed between feed and the point of disturbance is activated, but the sets after disturbance point is inactive. So operator, with finding the last set, finds out that the fault exists between the last active set and first inactive set, and as a result, it surveys only the considered zone. If they equipped with telecommunication systems, the fault signal are sent to the control center and only the considered zone is surveyed that, as a result, a less time will be spent for finding the fault placement.
In this paper, the optimum number of FIs in distribution automation system has been studied using the artificial immune algorithm. In this method, economical objective function is used for identifying suitable condition of FIs, and objective function and the answer of problem is posed as an antigen and possible solutions is indicated as an antibody [15-18]. Artificial immune algorithm as regards it simultaneously performs on the population of antibodies and it has possible rapid convergence respect to other algorithms such as genetic algorithm, and also other advantages of this algorithm is the ability of development on other optimization methods. In order to indicate the efficiency of

proposed method, the artificial immune algorithm has been used for optimal placement of FIs on a real Iranian distribution network. Result assessment indicated that the proposed algorithm for optimal placement of FIs, with regarding customer interruption cost has been effective and it can be used as an effective intelligent algorithm in distribution networks.

2. Modeling and Assessment Technique

When a permanent fault occurs in the network, faulted section of the network is detected with FI, and system operator is isolated faulted section with breakers and switches, and the sane section of the network is resupplying immediately. Faulted section has to be repaired and then resupplied [8]. Fault treatment process in network management has been indicated in Fig. 1

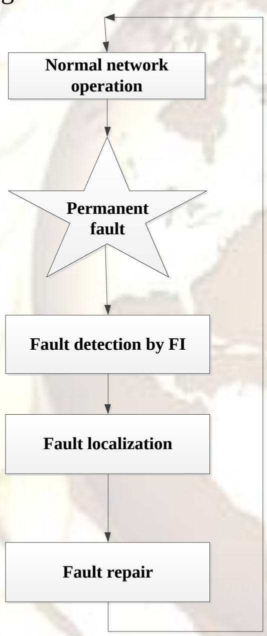

Fig 1: Fault treatment process in network management

The FI can decrease the process of fault detection, and it improved the reliability cost. For example a sample feeder with a FI, is shown in Fig. 2.

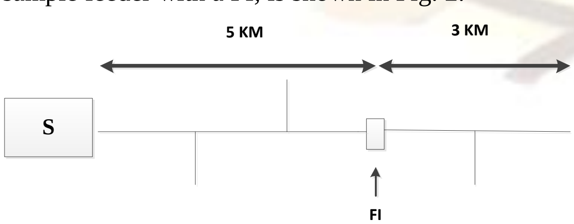

Fig 2: A Typical distribution system with one FI

Assume that the fault detection time of this feeder is 1 hour, and it is depended to feeder length. With installation of a FI, the fault locating time for upstream part of the feeder is:

$$1 \times \frac{5}{5+3} = 0.625 \qquad (1)$$

And the fault locating time for downstream part of the feeder is:

$$1 \times \frac{3}{5+3} = 0.375 \qquad (2)$$

In general, with installation of n FI on distribution feeder, that feeder is divided to n+1 part, and the fault locating time for *i* th part is calculated as follow:

$$(T_{detect})_i = T_0 \times \left(\frac{L_i}{\sum_{j=1}^{n+1} L_j} \right) \qquad i = 1, 2, 3, \ldots, n+1 \qquad (3)$$

Where

L_i: Length of part *i* th

T_0: average of fault locating time without FI

With calculation the fault locating time and also with regarding repair or switching time, and with application of customer damage function, can be calculating the customer interruption cost.

3. Customer Interruption Cost Evaluation

Estimate the reliability worth usually is done through evaluating the reliability index that indirectly reflects the worth of reliability. Reliability worth usually is evaluate as interruption cost, and can, for interrupted energy Assessment Rate or loss of Load Expectation, through statistical information that results in utilizing the elements of system.

Generally, in order to calculate the customer interruption cost, there is not a special rule and equation, and it specifically estimated through the estimation methods that can causes direct and indirect costs. Stop of the production line, putrefying nutrition and destruction of electrical equipment like computer from the effects of direct costs and damage related to the lack of production and sale, the problems of restarting is considered as the effects of indirect costs.

The cost that is caused from interruptions, it can be extremely different from a consumer to other consumer and from a country to the other country. Occurrence of interruption (in what year, what day of week or what hour of the day it has been occurred and/ or before the occurrence of fault, it has been warned or not, is very significant. If the consumer is equipped with generator of reservation or other emergency electricity systems, the rate of entered damage becomes less on them.

Interruption cost also rises with increase of time. Short-term interruptions can stop the production line and damage the equipment. Longer interruptions cause the lack of manufacturing production and fall of the existence of production [10, 11].

So, for assessment of the customer interruption cost, we need to identify the economical damage in a suitable way that is related to the consumers in the time of interruption occurrence. Economical damage that is emergent from interruption can be indicated in a customer damage function. This function can be estimated for each kinds of residential, commercial and or industrial customer. In order to obtain general damage function of the system, we can collect the damage function of residential, commercial, and

$$Minimize TCR = CIC + INVS \qquad (6)$$

industrial in that part of load until it obtains typically complex damage function [12-14]. Diagram (1) indicates the damage function of residential, commercial and industrial customer.

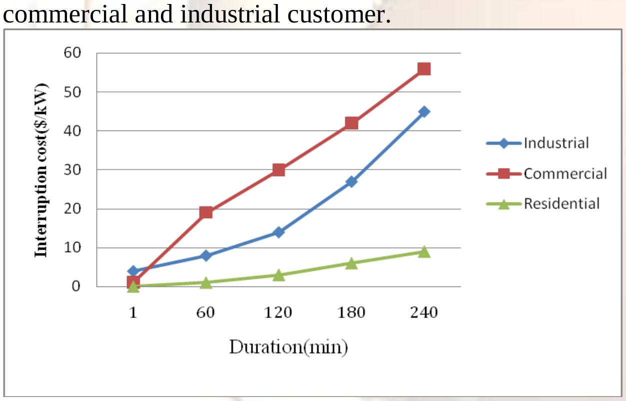

Diagram 1: Customer damage function for different sector

Interruption cost in distribution network can be shown with the following equation:

$$CIC = \sum_{i=1}^{n} IC_i = \sum_{i=1}^{n} \lambda_i l_i \left(\sum_{j=1}^{n} C_{ij} L_j \right) \qquad (4)$$

Where

n total number of line segment;

IC_i interruption cost per year due to outage in line segment i;

λ_i outage rate (failure per year/Km) of line segment

L_i length of line segment i;

C_{ij} interruption cost of load at segment j due to an outage at segment i;

L_j total load of line segment j;

C_{ij} is Interruption cost of residential, commercial, industrial customers and priority customers that is calculated as follow:

$$C_{ij} = \left(\mathrm{Res}_j . f_R(r_{ij}) + Com_j . f_C(r_{ij}) + Ind_j . f_I(r_{ij}) + \sum_{l=1}^{3} \mathrm{Pr}i_j^l . f_p^l(r_{ij}) \right) \qquad (5)$$

Where, in this equation Res, Com, Ind and pri is load percentage of residential, commercial, industrial and priority customers respectively, and f_r, f_c,f_I and f_p is residential, commercial, industrial and priority customer damage function respectively, and r_{ij} duration of service interruption of segment *j* due to a outage at segment *i*.

With calculating the interruption cost with using above equation and also the investment cost of FIs, we can obtain total cost of reliability with regard to the following method that is the final objective function for finding the optimal placement of FIs:

In this equation, CIC is the customer interruption cost and INVS is the investment cost of FIs.

4.1 Immune Algorithm

IA, as a research method and efficient optimization between other methods as genetic and intelligence algorithms, has a special situation. IA is a method that is derived from the approach of performance in immune system of body in facing with external diseases factors like viruses and bacteria and in a general framework of antigens, attack organism of creatures, they not only destroy the cells, but also produce the cells. One of the interesting mechanisms in defense system of creatures in facing with this attack is the fast production of defense cells that are very significant in identifying antigens and also destroying them. Interestingly, the rate of reproduction in defense cells and antibody is dependent on the rate of their success in destroying diseases Factors. It means that, the immune system reproduces more the defense cells with better performance, and it produces those lesser, who have less ability. The rate of recognition of an antigen is identified by defense cells with affinity factor. Defense cells with lesser affinity must tolerate a biological factors namely mutation until they can, with creating the changes in their own selves, increase their affinity with diseases factors, and they can improve the defense performance. Mutation for defense factors with more affinity, is lesser and conversely.

$$IE(N) = \frac{1}{M}\sum_{j=1}^{M} IE_j(N) \qquad (8)$$

4.2 Immune system of human body

In Immune system of cells, molecules and rules that have been organized, prevents against the attack of pathogens such as virus, bacteria and other guest hunger to body. One of the reactions of Immune system is transpiration of antibody by Lymphocytes of kind B. These antibodies are identifying with the Fig Y that are attached to the level of cell B. Lymphocytes of kind B with transpiration antibody identifies a part of antigen namely Epitope, and with making a strong join causes destroying the antigens [18-15]. In Fig. 3 the approach of join between antibody and antigen has been indicated.

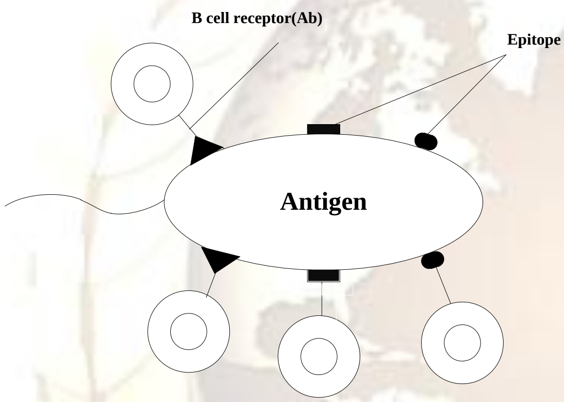

Fig 3: Antigen recognized by Antibody

In the introduced algorithm, objective function as an antigen and solutions of problem in search space is indicated as an antibody. During the process of optimization, the antibody that has most affinity with antigen is selected as a best solution. Parameters of diversity and affinity is calculated and used constantly during the approach of algorithm.

4.3.1 Diversity

To prevent local optimal solution in the evaluation process the diversity is measured between the antibodies. Antibodies that have more diversity and, with regard it, low affinity, is selected. In order to

$$IE_j(N) = -\sum_{i=1}^{n} P_{ij}\log P_{ij} \qquad (7)$$

measure the diversity between antibodies the concept of information Entropy has been used. Based on the concept of information Entropy, Entropy of *j*th gene (j=1,2,…,M) is expressed as follow:

In this equation P_{ij} is the probability the *i*th allele comes out the *j*th gen. if all of alleles in *j*th gene are same, the entropy of *j*th gene will be Zero.

Using equation (7), the average of information entropy will be calculated by the following method:

In this equation, M is the number of genes in antibody. Entropy indicates the diversity between the populations of antibodies [19].

4.3.2 Affinity

During the optimization procedure, two kind of affinity are assessed alternatively the first one is the affinity between the antibodies and the second is the affinity between antibody and antigen. Affinity between the *i*th antibody and *j*th antibody is calculated as follow:

$$Affinity_{(i,j)} = \frac{1}{1+IE(2)} \qquad (9)$$

In this equation IE(2) is the affinity between the *i*th antibody and *j*th antibody. $Affinity_{(i,j)}$ will be within the range [0,1].

Affinity between antibody *i* and antigen is calculated by the following equation:

$$(Ag)_i = \frac{1}{1+TCR} \qquad (10)$$

In this equation, TCR has been considered as an objective function of problem. The best answer is obtained when TCR has minimum amount. Fig (4) indicates information Entropy and the structure of genes in the framework of antibody.

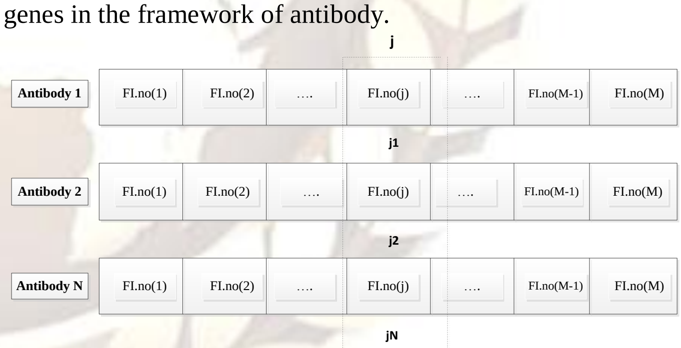

Fig 4: Data structure of genes and corresponding information entropy

5. Computation Procedures

Stages of Performing Algorithm In order to perform the IA, in solving the problem of finding the optimal placement of FIs, we perform like the trend of Fig 5 shown.

Step 1: Presentation of Data Structure: In this stage, the load points, switch, reliability parameters of lines are given as an input data to the program.

Step 2: Production of initial antibody population: A number of antibodies are produced randomly in the space of solving problem.
Step 3: Affinity calculations: In this stage, the affinity between antibodies Affinity $_{(i,j)}$, and affinity between antibody and antigen $(Ag)_i$ is calculated.
Step 4: Evaluation and selection: The antibodies that have high affinity with antigens are added to new memory cell. The antibodies that have been selected must have low affinity with other antibodies. In the other hand, in choosing the selected antibodies, antibodies are omitted if they have high affinity between their own selves.
Step 5: Crossover and mutation: After selecting the best antibodies, at first, the operation of crossover is performed on them, and with this approach that the existent population is divided in two groups (i.e. parents) and crossover with probability of P_c ($0<P_c<1$) is done randomly and in one-cut-point. Then the operation of mutation is done with probability P_m on selected population.
Step 6: Evaluate the fitness function: in this stage, the affinity is calculated between antibody and antigen, and maximum amount result is compared with most amount of prior population. With regard to existent progress in this parameter, the stage of algorithm is repeated until the most suitable places are obtained for the FIs.

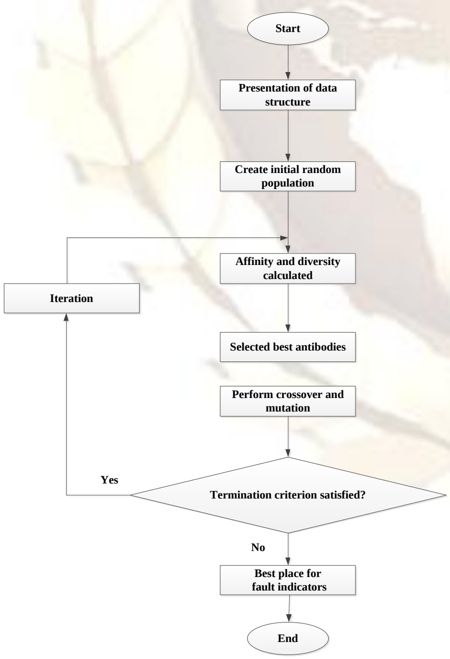

Fig 5: Flowchart of fault indicators placement by IA

6. Implementation of proposed algorithm in test system

In order to perform the proposed algorithm for finding optimal placement of FI, the computer programming has been prepared with using the MATLAB software that the investment cost of FIs and the approach of calculating the customer interruption cost have been included in program. The investment cost of three phases FIs with remote access has been considered 960$ per year with a life cycle of ten years [9]. Also cost of communication equipment is added to the FIs.

The test system has been indicated in Fig. 6. This system is a real distribution network in Tehran. In this network, there are 16 load points, and a number of customers and the average of load point has been shown in table (1). Reliability parameters in table (2) and also composite customer damage function have been considered in table (3). The first of each section has been considered as a place of FIs installation and time detection of fault place without FI that is one hour and fault detection with communication capability for FI is regard 5 minutes.

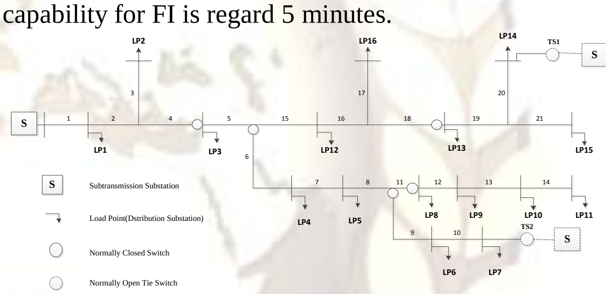

Fig 6: Test system

In proposed algorithm, in order to obtain the fast convergence, the population of antibody, crossover rate and the mutation rate has been considered respectively 100, 0.8 and 0.15. With performing the algorithm sections 2,4,7,11,15 and 19, most suitable places are obtained for installing the FI. Simulation parameters for IA and Genetic Algorithm (GA) have been considered in table (4).

Table 1: Simulation parameters

Algorithm	New population	Cross over	Mutation	Memory cell
Immune	100	0.8	0.15	50
Genetic	100	0.6	0.2	-

Diagram 2 indicates the customer interruption cost before and after installing the FI at each load point. The interruption cost of network, before and after installing the FI is, respectively, decrease from

72352$ to 39667$ per year, that annually has decreased 32685$.

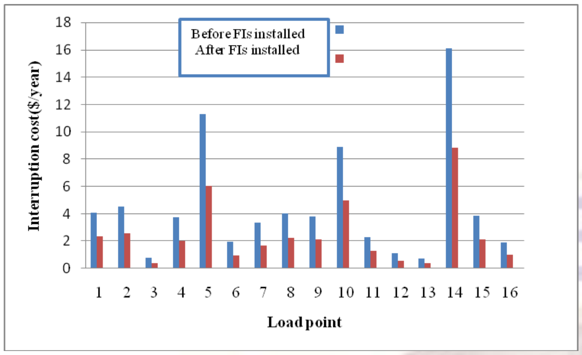

Diagram 2: CIC before and after FIs installed

Diagrams of (3), (4), (5) and (6) also indicate the reliability indexes before and after installing the FI, that significant, reliability improved after FIs installation.

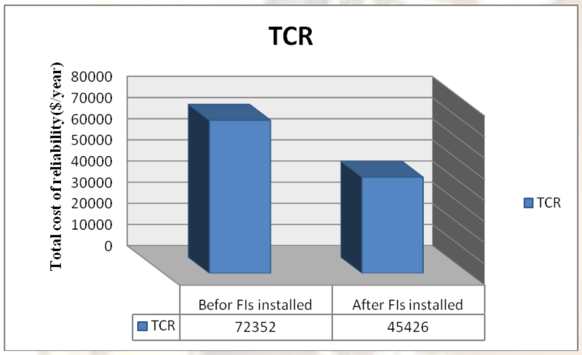

Diagram 3: TCR before and after FIs installed

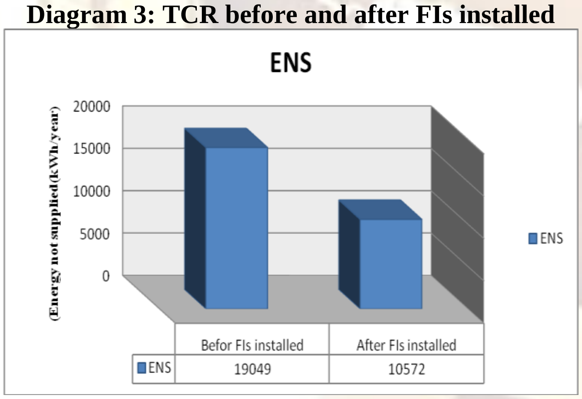

Diagram 4: ENS before and after FIs installed

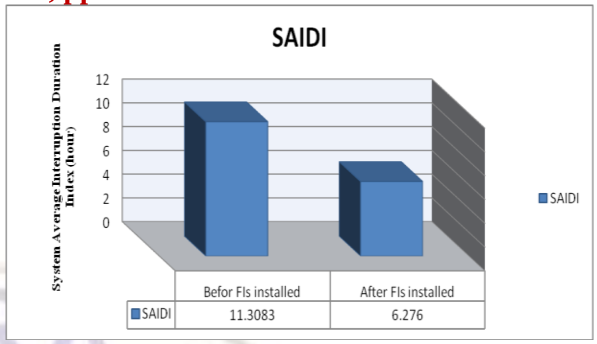

Diagram 5: SAIDI before and after FIs installed

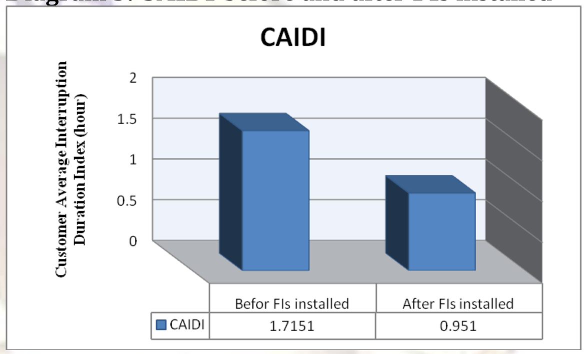

Diagram 6: CAIDI before and after FIs installed

In diagram (7), the IA and GA for finding the optimal location of FIs with the same objective function that has been compared, indicates that the IA, with 12 iteration and GA with 19 iteration, has gotten to optimal placement in objective function that fast convergence in IA in compared with GA.

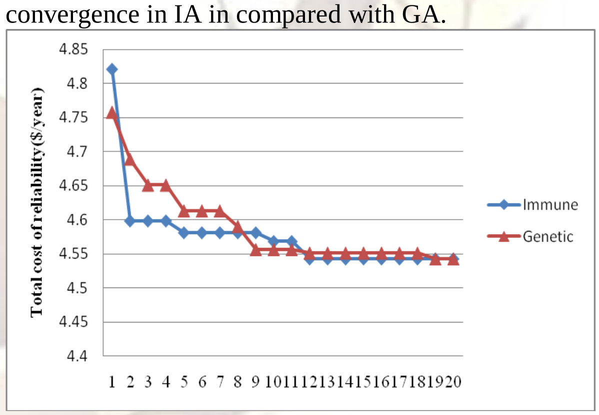

Diagram 7: Comparison between the IA and GA

7. Conclusions

This paper has presented an optimization problem to minimize the total cost of reliability of distribution network by optimal placement of fault indicators. The customer interruption cost, and the investment cost, repair and keeping cost of fault indicators are considered as the parameters of the objective function. The artificial immune algorithm is used to solve the proposed formulation. The proposed approach has been applied to a real Iranian distribution network, and the effectiveness of the IA-based method to solve this optimization problem has been demonstrated through the results obtained. Various indices of reliability are studied to show the effectiveness of optimal FIs' installation in distribution network. The results indicate the efficiency of proposed algorithm in finding the optimal placement of FIs and considerable decrease of customer interruption cost per year emphasizes the efficiency of IA in distribution networks.

Appendix

Table 2: Load data for distribution feeder [5]

Load point number	Average load [kW]	Number of customer
1	90	137
2	100.1	126
3	18.7	20
4	90	284
5	269.5	210
6	50.6	57
7	87.6	135
8	90	172
9	85	170
10	200	190
11	51.04	56
12	26.4	38
13	16.5	10
14	374	280
15	90	204
16	45.1	49
sum	1684.54	2138

Table 3: Reliability data for distribution feeder [5]

Section Number	Length [km]	Failure Rate [f/yr.km]	Repair Time [h]	Switching Time [h]
1	0.42	1.49	1.5	0.5
2	0.25	1.49	1.5	0.5
3	0.294	1.49	1.5	0.5
4	0.411	1.49	1.5	0.5
5	0.19	1.49	1.5	0.5
6	0.19	1.49	1.5	0.5
7	0.34	1.49	1.5	0.5
8	0.11	1.49	1.5	0.5
9	0.124	1.49	1.5	0.5
10	0.03	1.49	1.5	0.5
11	0.124	1.49	1.5	0.5
12	0.2	1.49	1.5	0.5
13	0.14	1.49	1.5	0.5
14	0.104	1.49	1.5	0.5
15	0.167	1.49	1.5	0.5
16	0.189	1.49	1.5	0.5
17	0.033	1.49	1.5	0.5
18	0.138	1.49	1.5	0.5
19	0.481	1.49	1.5	0.5
20	0.2	1.49	1.5	0.5
21	0.29	1.49	1.5	0.5
sum	4.425	-	-	-

Table 4: Load point CCDF [10]

Duration	[$/kw]
1 min	0.153
20 min	1.2434
1 hr	3.71
4 hr	15.4552
8 hr	42.6172

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