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Optimized operation and maintenance costs to improve system reliability by decreasing the failure rate of distribution lines

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Abstract: Improving distribution system reliability has received a great deal of attention in recent years. Because of the limitation in expected budgets, it is desirable to determine the most efficient strategy to improve system reliability. This paper proposes a novel method to determine the optimized operation and maintenance costs in order to decrease the failure of system components. The proposed objective function includes the average system frequency interruption index (ASIFI) value. To achieve the best strategy to decrease failures of system components, it is necessary to find the minimum value of the objective function, considering the constraints of operation and maintenance costs. A genetic algorithm is used to solve the optimization problem. Moreover, a new mathematical model to calculate system reliability indices, including the ASIFI, is introduced. The proposed method is applied to a realistic distribution system. The results illustrate the effectiveness of the proposed method in order to increase the system reliability in an optimal manner.

Key words: Average system interruption frequency index, failure rate, optimization, genetic algorithm, distribution systems

1. Introduction

The deregulation of electricity markets has urged the restructuring of vertically integrated power systems to generation, transmission, and distribution corporations. With this separation, electric utilities and network operators have focused on more reliable and profitable operation of power system corporations [1]. This is why, according to the customer failure statistics in [2] and [3], distribution systems have the most significant contribution to customer interruptions. Thus, most of the distribution network operators (DNOs) have tried to improve system reliability in an economic way.

A great deal of attention has been paid by researchers to propose methodologies aimed at improving distribution system reliability. These methodologies are generally based on the optimal placement of switches, reclosers, and protective devices in distribution systems [4–12]; adopting distributed generation (DG) [13–17]; and system reconfiguration solutions [18]. In recently published works [19,20], methodologies were proposed that aimed at improving distribution system reliability by reducing the failure rate and repair time of power system components. However, less attention has been paid in these studies to prioritize power system components for being subjected to decrease the failure of system components and repair time. This is why, in practical applications, a prioritized scheme is required to allocate the limited budget to enhance system reliability. Furthermore, there are several methods to reduce the failure rate of distribution systems, such as using shield

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wires and replacing overhead lines with cable sections, as well as reducing the operating temperature of lines, e.g., by capacitor placement throughout the network. However, the existing methods seem to be unable to choose the most critical components in the power system and the most economical way to improve system reliability when the budget is limited. Thus, further work is needed to fill the knowledge gap in this area of research.

This paper tries to fill such a knowledge gap by bringing 2 main contributions into the existing literature. First, a novel method is proposed to calculate reliability indices in distribution networks. Using the proposed method, it is possible to simply recalculate system reliability indices after any change in the reliability parameters of the system components. Next, an optimization formulation is proposed to determine the most important system components that affect system reliability indices. The proposed method in this paper uses an objective function based on the average system interruption frequency index (ASIFI), which is one of the most commonly used load-based reliability indices (see [21] and [22] for more details). The limited budget available for reliability improvement and the lower bound of the ASIFI are both considered as constraints in the problem formulation. A genetic algorithm (GA) is used to solve the optimization problem. The proposed methods are applied to a realistic distribution network in Tehran city center.

This paper is organized as follows. Section 2 addresses the presented approach for the reliability modeling of distribution systems. The optimization algorithm of the objective function is proposed in Section 3. Numerical results are discussed in Section 4, and conclusions are given in Section 5.

2. Problem formulation

The main purpose of this paper is to optimize distribution system reliability and its associated costs by reducing the failure rate of the most critical power system components. This is performed by introducing an objective function based on the ASIFI. The operation and maintenance budget available to reduce the failure rate of the network components and the minimum acceptable value of the ASIFI are considered as the constraints of the optimization problem. The proposed objective function is as follows:

$$\begin{array}{l} O.F = ASIFI \\ \text{subject to} \quad \sum_{j\in\beta} CC_j \leq C \end{array} \tag{1}$$

The definition of the ASIFI is presented by Eq. (2) [21]:

$$\text{ASIFI}=\frac{\text{Connected kVA Interrupted}}{\text{Total Connected kVA Served}} \tag{2}$$

It is noted that the proposed method only considers permanent faults and all of the temporary faults are assumed to be clear by reclosers. Moreover, the fuse saving overcurrent protection philosophy is used in the introduced method.

As mentioned in Section 1, a novel simplified reliability calculation method is presented in conjunction with the optimization formulation to calculate the reliability indices of distribution networks. Eqs. (3)–(10) introduce the main formulations of the method. They are used in this paper to calculate the ASIFI. However, the proposed formulations are general and can be used to calculate other reliability indices.

The simplified method of the reliability calculation is based on 2 factors, nominated as F_1 and F_2. These factors use the network topology, the number of customers connected to each load point, and the probability of a fault occurrence in each feeder section to calculate the number/amount of interrupted customers/loads when a given fault occurs in distribution networks.

Generally, all of the faults of the distribution network are classified into 2 groups. The first group contains those occurring in the main sections and the second is dedicated to the faults in the lateral branches. F_1 and F_2 calculate the interrupted customers/loads of the network for the faults in the main and lateral branches, respectively.

$$F_1(X,\lambda) = \sum_{i=1}^{mb} \lambda_{mi} \left(\begin{array}{l} \sum\limits_{j=i}^{mb} X_{mj} + \sum\limits_{k=1}^{i-1, i\neq 1} A(k+1,i) \times X_{mk} + \sum\limits_{s=1}^{flb_i} \sum\limits_{p=1}^{ts_s} X(s,p) \\ + \sum\limits_{q=1}^{blb_i} \sum\limits_{r=1}^{ts_q} A(fdmb_q, i) \times X(q,r) \end{array} \right) \tag{3}$$

Here, $A(i,j)$ is a function defined to simplify the calculation procedure, and is defined as follows:

$$A(i,j) = \begin{cases} 1 & \textit{protective device exists in position i to j} \\ 0 & \textit{otherwise} \end{cases} \tag{4}$$

As can be inferred from Eq. (3), F_1 is a function of the failure rates of the network sections, as well as the loads connected to each section. To explain this factor more clearly, a sample fault is shown in Figure 1, together with its resulting interrupted areas. As can be seen from Figure 1, the fault has occurred on the main branch and the interrupted customer/loads are divided into 4 groups. The first 2 groups correspond to the customers/loads connected to the main branch, downstream and upstream of the fault point, respectively. Eqs. (5) and (6) show the terms corresponding to each group, in F_1.

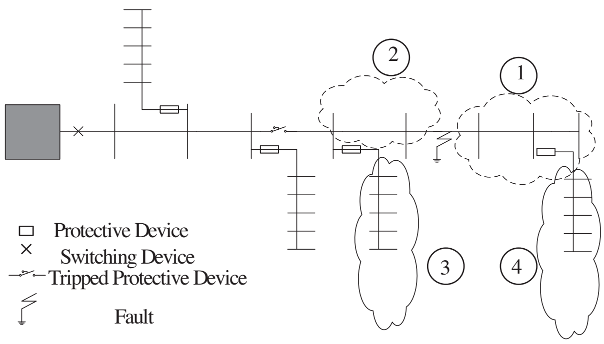

Figure 1. Typical schematic to illustrate the method used to calculate F_1.

$$\sum_{j=i}^{mb} X_{mj} \tag{5}$$

$$\sum_{k=1}^{i-1, i\neq 1} X_{mk} \times A(k+1,i) \tag{6}$$

Similarly, the terms corresponding to the other 2 groups of customers/loads, i.e. those connected to the lateral sections, downstream and upstream of the faulted point, respectively, are demonstrated by Eq. (7).

$$\sum_{s=1}^{flb_i} \sum_{p=1}^{ts_s} X(s,p) + \sum_{q=1}^{blb_i} \sum_{r=1}^{ts_q} X(q,r) \times A(fdmb_q, i) \tag{7}$$

F_2 shows the number/amount of interrupted customers/loads when a fault occurs in a lateral branch. If there is a protective device in each section of the lateral branch, the interruption would be sensed only by the customers/loads connected to the faulted lateral branch. Otherwise, all of the customers/loads downstream of the nearest protective device would experience an interruption. Figure 2 illustrates the interrupted areas for a fault at a lateral branch.

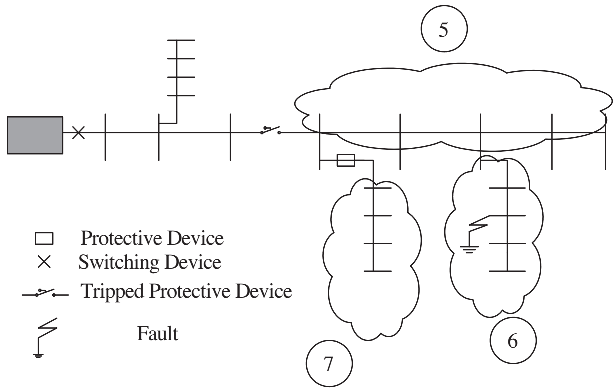

Figure 2. Typical schematic to illustrate the method used to calculate F_2.

$$F_2(X,\lambda) = \sum_{s=1}^{flb_i}\sum_{p=1}^{ts_s}\lambda_{s,p}\times\left(\begin{array}{l}\sum\limits_{j=1}^{mb} L_{mj}\times A(1,p)+\sum\limits_{t=1}^{flb_{fdmb_s}}\sum\limits_{p=1}^{ts_t} L_{t,p}\times A(1,w)+\\ \sum\limits_{v=1}^{blb_{fdmb_s}}\begin{array}{l}\sum\limits_{y=1}^{ts_v} L_{v,y}\times A(fdmb_s,fumb_s)\times A(l,w)+\\ \sum\limits_{l=1}^{fumb_s-1} L_{ml}\times A(l,p)\times A(l,fdmb_s)\end{array}\end{array}\right) \quad (8)$$

In Figure 2, the interrupted customers/loads are divided into 3 groups. Interrupted area 5 shows the customers/loads connected to the main branch. In contrast, interrupted areas 6 and 7 indicate the customers/loads located at lateral branches. Under this circumstance, Eqs. (9) and (10) show the mathematical formulation to calculate the number/amount of customers/loads connected to the main and lateral branches, respectively.

$$F_{2-1}(X,\lambda) = \sum_{j=1}^{mb} L_{mj}\times A(1,p) + \sum_{l=1}^{fumb_s-1} L_{ml}\times A(l,p)\times A(l,fdmb_s) \quad (9)$$

$$F_{2-2}(X,\lambda) = \sum_{t=1}^{flb_{fdmb_s}}\sum_{p=1}^{ts_t} L_{t,p}\times A(1,w) + \sum_{v=1}^{blb_{fdmb_s}}\sum_{y=1}^{ts_v} L_{v,y}\times A(fdmb_s,fumb_s)\times A(l,w) \quad (10)$$

Based on Eqs. (3)–(10), the definition of the ASIFI can be modified as follows:

$$ASIFI = \frac{\sum_{i=1}^{2} F_i}{S} = \frac{F_1(X,\lambda)+F_2(X,\lambda)}{S}. \quad (11)$$

$where\ X =$ the value of the installed loads

When a distribution system is in operation with its protective devices installed, the ASIFI is a function of the failure rate of the system components. The compensation level is defined based on the compensated and uncompensated failure rates of a system component, as shown by Eq. (12).

$$CR_j = \frac{\lambda_{j,uncomp} - \lambda_{j,comp}}{\lambda_{j,uncomp}} \tag{12}$$

It should be noted that the introduced methodology is focused on pure radial distribution networks. However, it is possible to apply it to systems with feeder ties after some modifications.

3. Objective function optimization

The capital cost needed to reduce the failure rate of each line section can be expressed as a function of the compensation level, as shown by Eq. (13). According to the literature [23,24], simple actions such as pruning trees and reducing the current flow through the line sections can improve their failure rates up to 85% of those without compensation, and for further reductions in the failure rates, much more capital cost would be needed. This concept is modeled by the 3-sectional function of Eq. (13), and is shown in Figure 3.

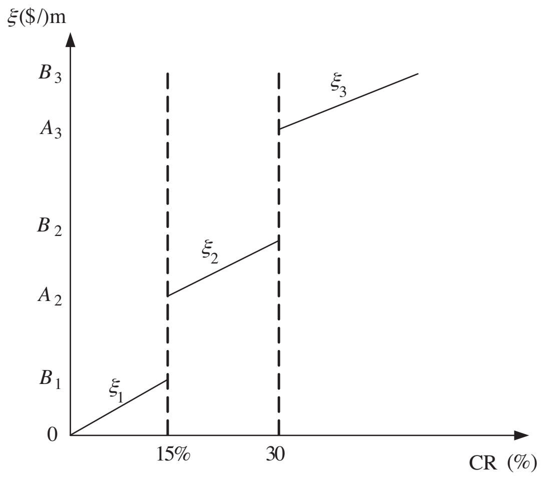

Figure 3. Cost-compensation rate.

$$c_j = \begin{cases} D_j \times \zeta_1 & \text{if} \quad 0\,\% \leq CR_j \leq 15\% \\ D_j \times \zeta_2 & \text{if} \quad 15\% \leq CR_j \leq 30 \\ D_j \times \zeta_3 & \text{if} \quad CR_j \geq 30\% \end{cases} \tag{13}$$

Figure 3 shows the capital cost needed to reduce the failure rate of the line sections as a function of the compensation level. As is shown, 3 sections are defined for the cost function. By taking this approach, the capital cost can be calculated in each section based on Eq. (14).

Due to the complexity of realistic distribution networks, the use of intelligent methods seems to be inevitable when the proposed method is applied to realistic case studies. Several intelligent optimization methods such as the GA [6,10,11], ant colony system [8,13], tabu search [7], and simulated annealing [6] have been used in previous works. In this paper, a GA is used to solve the proposed optimization problem, by representing each line section with a gene within the GA's chromosomes. Figure 4 shows the flowchart of the optimization procedure.

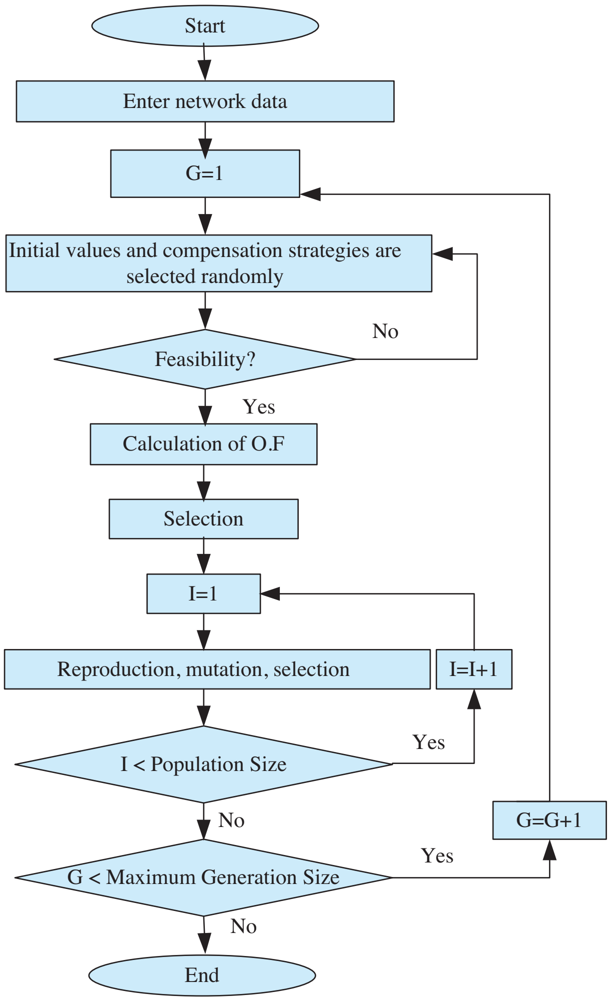

Figure 4. Flowchart of the optimization process based on the GA.

$$\begin{aligned} \zeta_1 &= \tfrac{100}{15}\left(B_1\right)\left(CR_i\right) \\ \zeta_2 &= A_2 + \tfrac{100}{15}\left(B_2 - A_2\right)\left(CR_i - 15\%\right) \\ \zeta_3 &= A_3 + \tfrac{100}{15}\left(B_3 - A_3\right)\left(CR_i - 30\%\right) \end{aligned} \tag{14}$$

4. Numerical results

The proposed methods in Sections 2 and 3 are applied here to a realistic distribution network in the Tehran city center. Figure 5 shows a single line diagram of the distribution network, together with the installed protective and switching devices. Table 1 presents the general data of the network. Furthermore, the allocation of the protective devices to the network branches is shown in Table 2.

Table 3 presents the numerical values of the coefficients used in the proposed objective function. These values are extracted from the available experimental data of the Tehran Regional Electricity Company (TREC), the entity responsible for the operation and maintenance of the network under study.

Table 1. System parameters.

Branch no.	Installed load (kVA)	Length (m)	Permanent failure rate (m)	Branch no.	Installed load (kVA)	Length (m)	Permanent failure rate (F/year)	Branch no.	Installed load (kVA)	Length (m)	Permanent Failure rate (F/year)
1	0	80	0.016	62	100	50	0.01	123	0	30	0.006
2	0	50	0.01	63	0	160	0.032	124	0	50	0.01
3	50	400	0.08	64	0	350	0.07	125	200	150	0.03
4	0	500	0.1	65	100	50	0.01	126	100	310	0.062
5	250	50	0.01	66	0	15	0.003	127	0	200	0.04
6	0	400	0.08	67	100	180	0.036	128	100	300	0.06
7	0	100	0.02	68	200	360	0.072	129	500	150	0.03
8	200	200	0.04	69	100	420	0.084	130	0	120	0.024
9	315	80	0.016	70	200	240	0.048	131	0	130	0.026
10	0	230	0.046	71	160	120	0.024	132	100	10	0.002
11	100	210	0.042	72	500	210	0.042	133	100	400	0.08
12	25	400	0.08	73	0	70	0.014	134	160	420	0.084
13	0	1050	0.21	74	100	300	0.06	135	0	60	0.012
14	0	20	0.004	75	0	20	0.004	136	0	150	0.03
15	0	20	0.004	76	200	250	0.05	137	0	150	0.03
16	50	300	0.06	77	160	240	0.048	138	200	120	0.024
17	0	40	0.008	78	0	120	0.024	139	200	120	0.024
18	0	370	0.074	79	100	240	0.048	140	0	220	0.044
19	50	15	0.003	80	315	160	0.032	141	100	10	0.002
20	200	100	0.02	81	200	120	0.024	142	0	220	0.044
21	0	10	0.002	82	0	380	0.076	143	0	40	0.008
22	0	30	0.006	83	100	15	0.003	144	0	120	0.024
23	0	30	0.006	84	25	70	0.014	145	200	40	0.008
24	0	100	0.02	85	200	300	0.06	146	0	60	0.012
25	200	50	0.01	86	0	140	0.028	147	50	15	0.003
26	100	210	0.042	87	200	10	0.002	148	50	240	0.048
27	0	420	0.084	88	100	330	0.066	149	0	200	0.04
28	315	80	0.016	89	0	140	0.028	150	200	240	0.048
29	0	150	0.03	90	250	550	0.11	151	0	330	0.066
30	100	420	0.084	91	0	5	0.001	152	200	1600	0.32
31	160	450	0.09	92	200	570	0.114	153	0	250	0.05
32	100	10	0.002	93	0	1000	0.2	154	200	150	0.03
33	400	220	0.044	94	0	30	0.006	155	315	250	0.05
34	0	10	0.002	95	50	500	0.1	156	100	60	0.012
35	315	150	0.03	96	0	350	0.07	157	0	180	0.036
36	315	340	0.068	97	50	100	0.02	158	50	150	0.03
37	400	200	0.04	98	315	50	0.01	159	0	400	0.08
38	0	250	0.05	99	315	300	0.06	160	0	500	0.1
39	0	50	0.01	100	200	300	0.06	161	100	10	0.002
40	0	350	0.07	101	50	630	0.126	162	0	900	0.18
41	0	360	0.072	102	0	10	0.002	163	0	60	0.012
42	0	100	0.02	103	0	50	0.01	164	200	850	0.17
43	425	140	0.028	104	0	60	0.012	165	0	70	0.014
44	0	10	0.002	105	0	50	0.01	166	0	30	0.006
45	0	40	0.008	106	100	15	0.003	167	0	450	0.09
46	0	40	0.008	107	0	180	0.036	168	50	450	0.09
47	0	500	0.1	108	0	40	0.008	169	0	150	0.03
48	0	630	0.126	109	250	60	0.012	170	50	50	0.01
49	50	10	0.002	110	250	200	0.04	171	50	200	0.04
50	200	600	0.12	111	0	15	0.003	172	0	120	0.024
51	200	10	0.002	112	100	15	0.003	173	100	210	0.042
52	0	130	0.026	113	100	140	0.028	174	200	260	0.052
53	200	15	0.003	114	200	230	0.046	175	50	300	0.06
54	500	100	0.02	115	0	10	0.002	176	0	200	0.04
55	250	60	0.012	116	0	50	0.01	177	0	30	0.006
56	200	450	0.09	117	100	120	0.024	178	100	250	0.05
57	0	190	0.038	118	0	10	0.002	179	0	15	0.003
58	250	350	0.07	119	25	350	0.07	180	100	8	0.0016
59	0	180	0.036	120	0	370	0.074	181	250	120	0.024
60	0	180	0.036	121	0	360	0.072	182	0	20	0.004
61	500	350	0.07	122	0	40	0.008	183	200	250	0.05

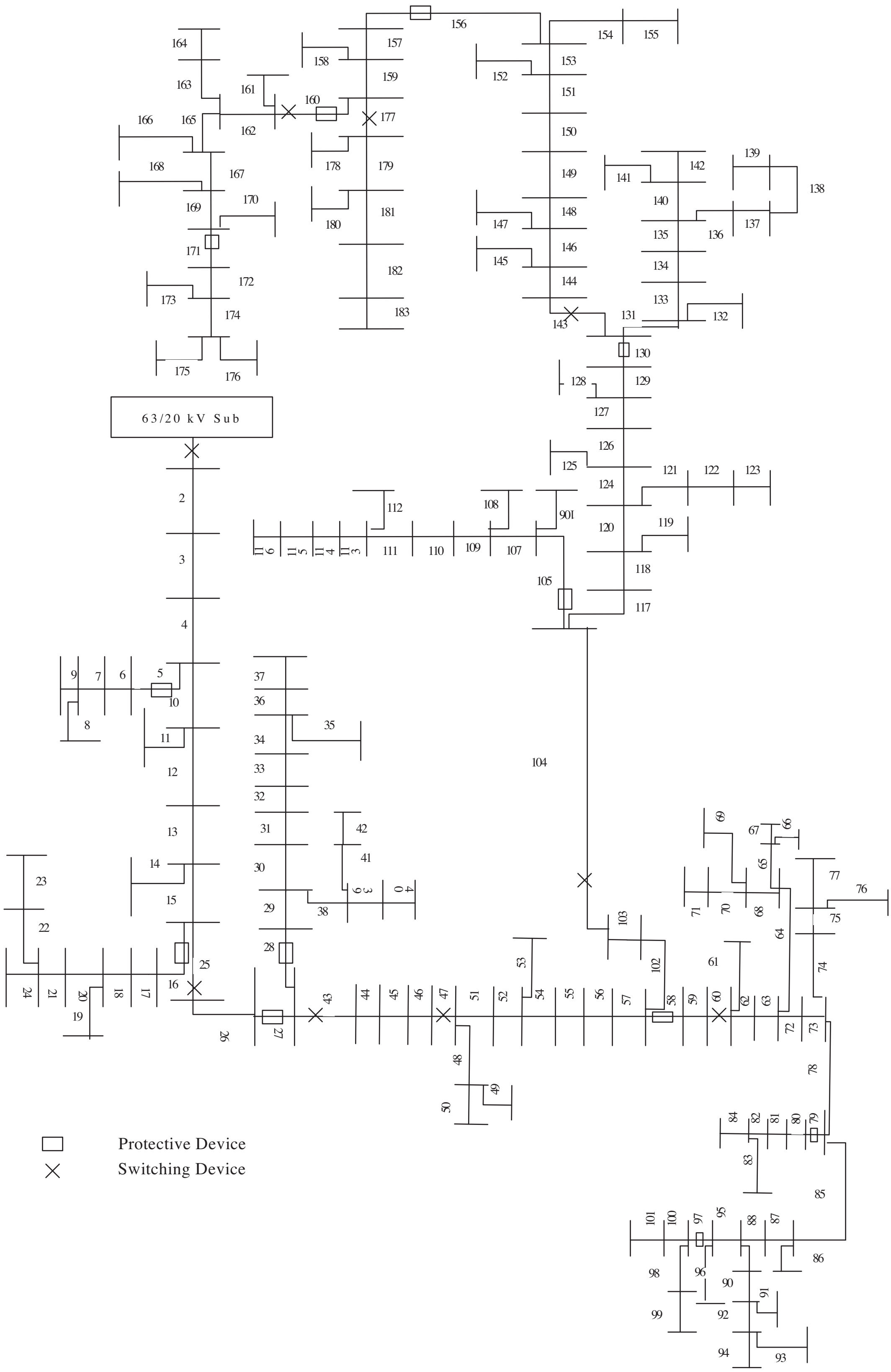

Figure 5. The 183-bus realistic distribution system.

Table 2. Placement of the protective and switching devices of the network under study.

Device type	Branch numbers
Fuses	5, 16, 27, 28, 58, 105, 130, 131,156, 160, 79, 97, 170, 171
Isolators	9, 14, 23, 42, 45, 46, 60, 104, 142, 160, 164, 183

The first compensation area is relevant to a maximum 15% reduction in the failure rates of the network lines. This can be obtained by economically appropriate approaches. Different methods, such as decreasing the current passing through lines using capacitors to supply the reactive power of loads or DGs, pruning trees, and the elimination of the natural barriers are recommended for the first compensation area [2,23]. The maximum cost of these compensations is considered to be US$40/m. More compensation in the second compensation area requires a higher cost because the resizing of the line conductors and shielding for lightning strikes should be performed for this compensation area. The minimum and maximum required costs within the second compensation area are $100 and $200/m, respectively. Furthermore, expensive fundamental changes are required in the third compensation area.

Figures 6 and 7 show the convergence of the optimization process for the 2 scenarios under study, respectively, and contain the results for both the best and average values of the objective function in each generation of the GA. The present value of the ASIFI is about 1.7855. Under the first case study (C is limited to $400,000 in this case), the optimum value of the ASIFI, as can be seen from Figures 6 and 7, gets reduced to 1.6306 (about 91% of the base case). By doubling the available budget for the reliability improvement, the optimum value of the ASIFI may even reach 1.4786 (83% of that of the base case).

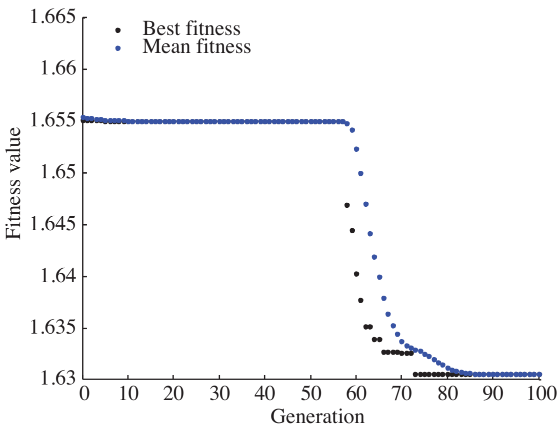

Figure 6. Convergence of the optimization process under the first scenario.

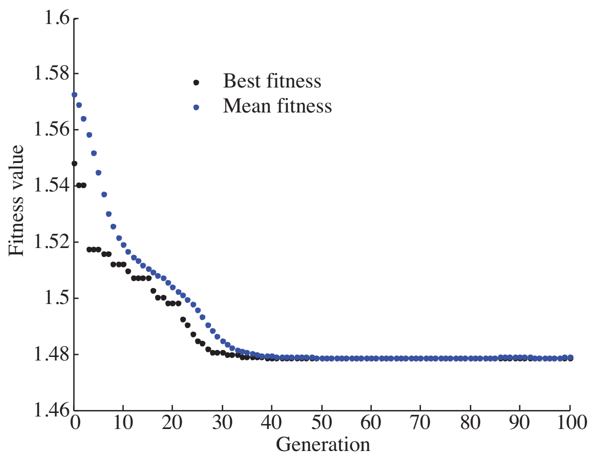

Figure 7. Convergence of the optimization process under the second scenario.

To put it more simply, it can be said that the TREC has $400,000 and $800,000 in cases 1 and 2, respectively, and the proposed method can obviously calculate the best ASIFI that can be achieved. It can further determine the line segments that are needed to be subjected to reliability improvement actions to achieve such an ASIFI.

Table 4 shows the compensation ratio (CR) for each line section based on the optimized solutions obtained for the scenarios under study. As can be seen, the CR of the sections located in the lateral branches is generally less than the ones located in the main branch. The results show that for the first scenario, the CRs of sections 61 to 72, 132 to 139, and 143 to 148, and for the second scenario, the CRs of sections 143 to 149 are approximately '0'. Furthermore, the maximum value of all of the CRs in first and second scenarios is '0.15'. In analyzing these results, it should be mentioned that all of the CRs are limited to 0.15. This is because of the significant difference in the compensation cost when the compensation area changes from one area to another.

Table 3. Economic parameters.

Parameter	Value ($/m)
A_2	100
A_3	300
B_1	40
B_2	200
B_3	500

Furthermore, in Figures 8 and 9, the plots of the compensation cost for all of the line sections are shown under the scenarios. As can be seen, the maximum value of the compensation costs are about $11,192 and $64,000, which belong to line sections 50 and 152. By analyzing the compensation cost allocated to each line section, it is possible to determine the most and the least important sections to improve the network reliability. Furthermore, as can be inferred from the results, most of the line sections that are not being recommended to decrease their failure rate are those located in the lateral branches with a protective device.

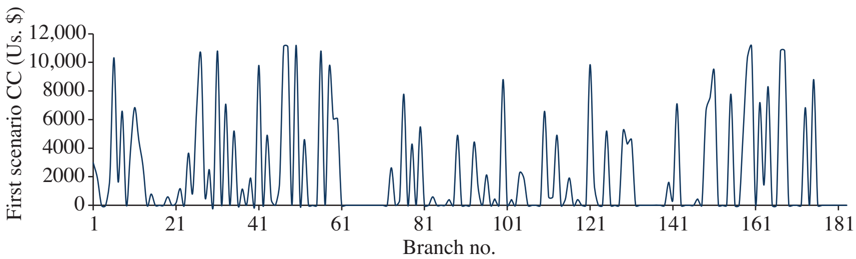

Figure 8. Compensation cost allocated to decrease the failure rate of each network section under the first scenario.

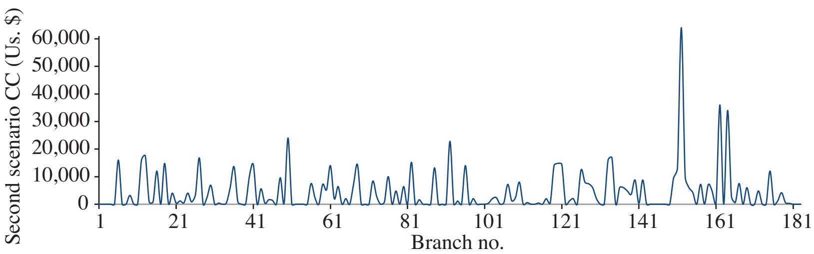

Figure 9. Compensation cost allocated to decrease the failure rate of each network section under the second scenario.

Table 4. Optimization results.

Branch No.	Scenario 1 CR	Scenario 2 CR	Branch No.	Scenario 1 CR	Scenario 2 CR	Branch No.	Scenario 1 CR	Scenario 2 CR
1	0.14	0.00	62	0.00	0.15	123	0.00	0.15
2	0.14	0.00	63	0.00	0.15	124	0.00	0.15
3	0.00	0.00	64	0.00	0.00	125	0.13	0.00
4	0.00	0.00	65	0.00	0.15	126	0.00	0.15
5	0.14	0.00	66	0.00	0.00	127	0.00	0.15
6	0.10	0.15	67	0.00	0.15	128	0.00	0.09
7	0.06	0.00	68	0.00	0.15	129	0.13	0.15
8	0.12	0.00	69	0.00	0.00	130	0.13	0.06
9	0.00	0.15	70	0.00	0.00	131	0.13	0.00
10	0.06	0.00	71	0.00	0.00	132	0.00	0.00
11	0.12	0.00	72	0.00	0.15	133	0.00	0.15
12	0.04	0.15	73	0.14	0.15	134	0.00	0.15
13	0.01	0.06	74	0.00	0.00	135	0.00	0.00
14	0.00	0.15	75	0.07	0.15	136	0.00	0.15
15	0.15	0.15	76	0.12	0.15	137	0.00	0.15
16	0.00	0.15	77	0.00	0.00	138	0.00	0.15
17	0.00	0.00	78	0.13	0.15	139	0.00	0.11
18	0.00	0.15	79	0.00	0.00	140	0.03	0.15
19	0.15	0.06	80	0.13	0.15	141	0.15	0.10
20	0.00	0.15	81	0.00	0.00	142	0.12	0.15
21	0.06	0.15	82	0.00	0.15	143	0.00	0.00
22	0.15	0.15	83	0.15	0.00	144	0.00	0.00
23	0.00	0.06	84	0.00	0.09	145	0.00	0.00
24	0.14	0.15	85	0.00	0.00	146	0.00	0.00
25	0.06	0.06	86	0.00	0.00	147	0.11	0.00
26	0.12	0.06	87	0.15	0.00	148	0.00	0.00
27	0.09	0.15	88	0.00	0.15	149	0.12	0.00
28	0.03	0.00	89	0.13	0.00	150	0.12	0.15
29	0.06	0.06	90	0.00	0.00	151	0.11	0.15
30	0.00	0.06	91	0.00	0.00	152	0.00	0.15
31	0.09	0.00	92	0.00	0.15	153	0.00	0.15
32	0.00	0.15	93	0.02	0.00	154	0.00	0.15
33	0.12	0.00	94	0.15	0.15	155	0.12	0.06
34	0.00	0.15	95	0.00	0.00	156	0.00	0.00
35	0.13	0.15	96	0.02	0.15	157	0.00	0.15
36	0.00	0.15	97	0.00	0.00	158	0.13	0.00
37	0.02	0.02	98	0.03	0.15	159	0.10	0.07
38	0.00	0.00	99	0.00	0.00	160	0.08	0.04
39	0.14	0.00	100	0.11	0.00	161	0.00	0.15
40	0.00	0.11	101	0.00	0.00	162	0.03	0.15
41	0.10	0.15	102	0.15	0.15	163	0.09	0.00
42	0.00	0.00	103	0.00	0.15	164	0.04	0.15
43	0.13	0.15	104	0.14	0.15	165	0.00	0.15
44	0.15	0.15	105	0.14	0.00	166	0.00	0.07
45	0.00	0.15	106	0.00	0.15	167	0.09	0.06
46	0.14	0.13	107	0.00	0.15	168	0.09	0.00
47	0.08	0.00	108	0.00	0.12	169	0.00	0.15
48	0.07	0.06	109	0.00	0.15	170	0.00	0.00
49	0.00	0.15	110	0.12	0.15	171	0.00	0.00
50	0.07	0.15	111	0.15	0.00	172	0.00	0.15
51	0.00	0.00	112	0.15	0.15	173	0.12	0.00
52	0.13	0.00	113	0.13	0.00	174	0.00	0.00
53	0.00	0.00	114	0.00	0.00	175	0.11	0.15
54	0.00	0.00	115	0.15	0.15	176	0.00	0.00
55	0.00	0.00	116	0.14	0.00	177	0.00	0.15
56	0.09	0.06	117	0.00	0.06	178	0.00	0.06
57	0.00	0.05	118	0.15	0.15	179	0.00	0.15
58	0.10	0.00	119	0.00	0.15	180	0.00	0.15
59	0.13	0.15	120	0.00	0.15	181	0.00	0.00
60	0.13	0.11	121	0.10	0.15	182	0.00	0.00
61	0.00	0.15	122	0.14	0.00	183	0.00	0.00

5. Conclusion

The reliability improvement of distribution systems has emerged as an important research area in recent years. Decreasing the failure rates of power system components has been an effective strategy to improve system reliability. In this paper, a novel method is proposed to optimize the required investment to improve distribution system reliability by decreasing the failure rate of the system components. The proposed method uses a GA as the optimization method and has set the objective function based on the ASIFI. Furthermore, it considers the limited budget available for the reliability improvement. The proposed method is applied to the realistic distribution system of Tehran city center. The obtained results illustrate the effectiveness of the proposed method. It is possible to determine the critical lines according to their importance on the system reliability and by decreasing the failure rate of these critical lines, the reliability improvement can be obtained optimally.

Nomenclature

T	Total number of customers connected to the distribution system
S	Total load demand of the distribution system, in MVA
F_1 and F_2	Mathematical functions that calculate the number of loads interrupted for faults in main and lateral sections
X	Input variables of defined functions to calculate reliability indices
C	Expected cost to improve system reliability by decreasing the failure of system components
CC_j	Cost of decreasing failure of section j
$\lambda_{j,comp}$	Compensated failure rate of section j
$\lambda_{j,uncomp}$	Uncompensated failure rate of section j
D_j	Length of section j
$O.F$	Objective function of the proposed optimization problem
mb	Number of sections located in the main branch
n	Total number of system sections
λ_{mi}	Failure rate of the ith section of the main branch
$\lambda_{s,p}$	Failure rate of the pth section from the sth lateral branch
N_{mi}	Number of customers supplied through the ith section of the main branch
L_{mi}	Amount of customer loads supplied through the ith section of the main branch
β	Set of candidate sections to decrease their failure rates
flb_i	First downstream lateral branch of section i from the main branch
$N_{s,p}$	Number of customers supplied through the pth section of the sth lateral branch
$L_{s,p}$	Amount of customer loads supplied from the pth section of the sth lateral branch
ts_s	Number of sections located in the sth lateral branch
blb_i	First upstream lateral branch of section i of the main branch
$fdmb_i$	First downstream main branch of the ith lateral branch
$fumb_i$	First upstream main branch of the ith lateral branch
ζ_i	Cost function of compensated area i
A_i	Lower bound of the compensation cost of area i
B_i	Upper bound of the compensation cost of area i
CR	Compensation ratio
CC	Compensation cost
G	Generation size
I	Algorithm iteration

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