Protective and Switching Devices Allocation According to Total Cost Minimization by Genetic Algorithm in Distribution Systems

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Abstract—**Protective and switching devices play an important role in system reliability. The placement of these devices affects the effects of them. In this paper, novel method is proposed to allocate the protective and switching devices in distribution systems .In the proposed method, energy not supplied (ENS) is selected to define a proper objective function to find the optimal solution. One of the most effective advantages of the proposed method is the cost-benefit analysis in solve the optimization problem. The practical distribution network is selected to apply the method. The obtained results illustrate the effectiveness of the method.**

***Index Terms*-- optimum protection, distribution networks, protective devices, switching devices, total cost, energy not supplied (ENS)**

I. Introduction

THe fundamental purpose of the electric utilities is to service their customers with a reliable and appropriate cost power supply. In the recent studies, the most common indices used about the power quality and reliability of the distribution systems are customer oriented indices. These customer oriented indices are system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI), average system interruption frequency index (ASIFI), average system interruption duration index (ASIDI), customer average interruption duration index (CAIDI), average system availability index (ASAI) and energy not supplied (ENS). These indices have been detailed in several relevant papers with the reliability of the distribution systems [1, 2].

Optimized and safe designing of distribution systems concludes the protective and switching devices in strategic places of the distribution networks to improve the reliability and power quality indices. Several papers are found in literature dealt with the optimized placement of protective and switching devices. References [3-7] survey separately the optimal switch allocation for network energy restoration. Other references have analyzed the optimized allocation of the protective devices in distribution systems [1, 8-10]. Also several papers proposed different methods to optimally place both switches and protective devices [11-14].

In the model proposed in [3], the objective function includes outage, capital cost and maintenance to find the optimal placement of the switches. In other reference [4], the proposed method has dealt with the comparison between cost of the non- supplied energy and cost of the sectionalizing switches. The algorithm used to solve the optimization problem is genetic algorithm. [8]. Binary linear programming model is used for the placement of protection devices, fault locators and other sensors in the distribution networks [1, 9]. In References [11, 13], the problem of the optimized switches and protective devices is modeled through non- linear programming (MINLP) with real and binary variables. The reactive taboo search algorithm (RTS) is used to solve the optimized problem. Ref [14] has presented a multi objective optimization methodology to optimally place of the switches and protective devices to improve the system reliability indices. The multi objective ant colony optimization (MACO) has been applied to solve the problem. The proposed placement of switches and protective devices leads to minimize the total cost while simultaneously minimize two distribution network reliability indices including SAIFI and SAIDI.

This article tries to determine the location of protective and switching equipment including recloser, sectionalizer, fuse and isolator. In this method a general program has been designed firstly to receive data of network with the several formats from database then energy not supplied index will be calculated. The cost of energy not supplied (CENS) and the cost of install, repair and maintenance of devices is considered as an objective function. New method is introduced to calculate the interrupted loads and restoration energy. The introduced method is based on the analytical methods. One advantage of the proposed method is the ability of calculating different indices. Genetic Algorithm (GA) is selected to solve the optimization problem. The proposed method is applying to a real distribution system. The results illustrate the effectiveness of the proposed method.

II. Objective function

In this paper, a new objective function is defined to

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optimize the protective and switching devices allocation. The introduced objective function includes total cost of the distribution system. The total cost of each distribution system is the cost of the energy not supplied and the devices cost.

In Eq.1 the proposed objective function is shown. The cost of energy not supplied is a variable cost, while the devices cost is a fixed cost. Therefore, the variable cost would be added to fixed cost by a coefficient. This coefficient concludes several parameters such as useful lifetime of devices, load growth and the interest rate. In equations (1-3), the definition of the objective function is explained. In these equations, TC, FC, r, t, and p are the total cost of the distribution system, the cost of the device install and maintenance, the interest rate, useful time of devices and the load growth, respectively.

$$\mathrm{TC} = \mathrm{FC} + \mathrm{K} \times \mathrm{CENS} \tag{1}$$

$$q = \frac{1 + r\%}{1 + p\%} \tag{2}$$

$$K = \frac{q^{t} - 1}{q - 1} \tag{3}$$

Equations used to calculate the CENS and FC are shown in (4-10). The method of calculating the reliability indices introduced in [16] is used to calculate the CENS. Five main functions calculate the load interrupted and restoration energy in the distribution system.

$$F_1(X) = \sum_{i=1}^{mb} \lambda_{mi} \left(\sum_{j=i}^{mb} X_{mj} + \sum_{k=1}^{i-1, i\neq 1} X_{mk} \cdot A(k+1, i) + \sum_{s=1}^{flb(i)} \sum_{p=1}^{ts(s)} X(s,p) + \sum_{q=1}^{blb(i)} \sum_{r=1}^{ts(q)} X(q,r) \cdot A(fdmb(q), i) \right) \tag{4}$$

$$F_2(X) = \sum_{s=1}^{flb(i)} \sum_{p=1}^{ts(s)} \lambda(s,p) \cdot \left(\sum_{j=1}^{mb} X_{mj} \cdot A(1,p) + \sum_{t=1}^{flb(fdmb(s))} \sum_{p=1}^{ts(t)} X(t,p) \cdot A(1,w) + \sum_{v=1}^{blb(fdmb(s))} \sum_{y=1}^{ts(v)} X(v,y) \cdot A(fdmb(s), fumb(s)) \cdot A(l,w) + \sum_{l=1}^{fumb(s)-1} X_{ml} \cdot A(l,p) \cdot A(l, fdmb(s)) \right) \tag{5}$$

Factor (1) and (2) are corresponded to interruption loads while fault occurs in network. Also factor (3), (4) and (5) calculate the restoration energy according to the ability of the switching devices. All variables used in these equations are explained in appendix.

To simplify the calculation of the introduced functions, two auxiliary functions are defined. The value of these auxiliary functions determines there is switching or protective device between two sections. The mathematical expressions of these functions are explained in E.qs (9) and (10).

The calculating the ENS and CENS are possible by using the introduced function. Because these functions are general, calculating the other reliability indices is easy. In Eqs. (11) and (12), the needed relations to calculate the ENS and CENS are explained.

$$F_3(X) = \sum_{i=1}^{mb} Y_{si} \left(\sum_{j=1}^{mb} \lambda_{mj} \cdot A(i,j) \cdot \sum_{k=1}^{i-1} X_{mk} \cdot A(k+1, i-1) \cdot B(k+1, i-1) + \sum_{n=flb(1)-flb(i)+1}^{flb(1)} \sum_{p=1}^{ts(n)} \lambda(n,p) \cdot A(1, ts(n)) \cdot A(i, fumb(n)) \cdot \sum_{q=1}^{i-1} X_q \cdot B(q+1, i-1) \cdot A(1, i-1) \right) \tag{6}$$

$$F_4(X) = \sum_{i=1}^{mb} Y_{si} \cdot \left(\sum_{j=1}^{mb} \lambda_{mj} \cdot A(i,j) \cdot \sum_{k=1}^{blb(i)} \sum_{l=1}^{ts(k)} X(k,l) \cdot A(fdmb, i-1) \cdot B(fdmb(k), i-1) + \sum_{n=flb(1)-flb(i)+1}^{flb(1)} \sum_{p=1}^{ts(n)} \lambda(n,p) \cdot A(1, ts(n)) \cdot A(1, fumb(n)) \cdot \sum_{q=1}^{blb(i)} \sum_{r=1}^{ts(q)} X(q,r) \cdot B(fdmb(q), i-1) A(fdmb(q), i-1) \right) \tag{7}$$

$$F_5(X) = \sum_{i=1}^{mb} Y_{si} \left(\left\{ \sum_{k=1}^{blb(i)} \sum_{l=1}^{ts(k)} \lambda(k,l) \cdot A(1,l) \cdot B(1, fumb(k)) + \sum_{w=1}^{i-1} \lambda_w \cdot B(1,w) \right\} \cdot Min\left(\left\{ \sum_{n=flb(1)-flb(i)+1}^{flb(i)} \sum_{p=1}^{ts(n)} X(n,p) + \sum_{v=i+1}^{mb} X_{mv} \right\}, \sum_{r\in\beta} M_r \cdot P_r \right) \right) \tag{8}$$

$$A(i,j) = \begin{cases} 1 & \text{if exist no protective object in position i to j} \\ 0 & \text{otherwise} \end{cases} \tag{9}$$

$$B(i,j) = \begin{cases} 1 & \text{if exist no switching object in position i to j} \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

$$ENS = \left[\sum_{i=1,2} F_i(L) \cdot T_1 - \sum_{i=3,4,5} F_i(L) \cdot T_2 \right] \tag{11}$$

$$CENS = \left[\sum_{i=1,2} F_i(L) \cdot CE - \sum_{i=3,4,5} F_i(L) \cdot (CE - CR) \right] \tag{12}$$

The main difference between Eqs. (11) and (12) is the cost coefficients and time coefficients. In Eq. (11), T_1 and T_2 are needed time to repair the interruption and restoration process by switching devices. The variables CE and CR are cost of the interruption and restoration while a fault occurs in system.

III. OBJECTIVE FUNCTION OPTIMIZATION

To find the optimum solution, the proposed objective function should be optimized. According to its non linear characteristic and complexity, optimization is not possible by using the conventional methods. Genetic algorithm is used to solve the optimization problem.

In Fig. 1, the flowchart of optimization by genetic algorithm is shown.

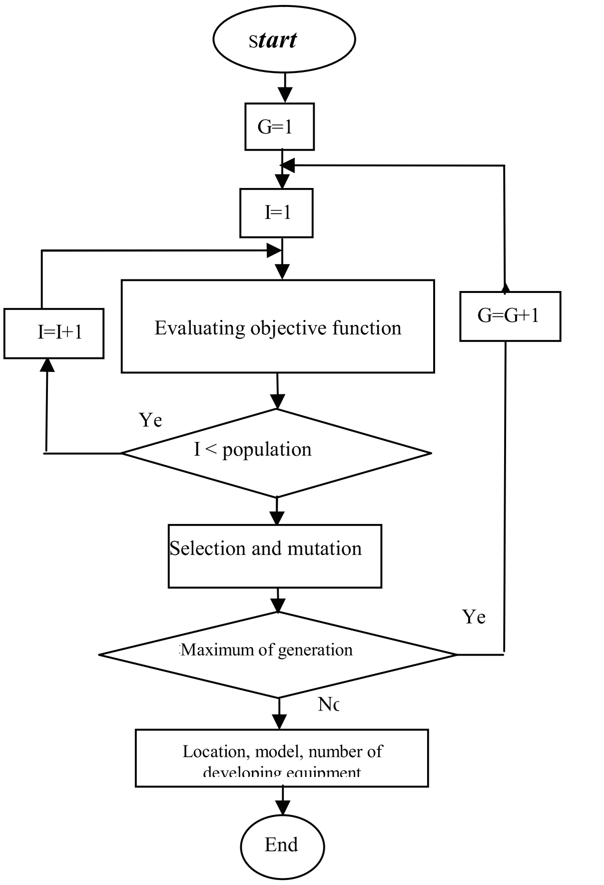

Figure 1: The flow-chart of the objective function optimization

IV. TEST RESULTS

To apply the method, a realistic distribution feeder is selected. The selected feeder is located in west of Tehran city. This feeder has 183 sections and works at 20 kV. The single line diagram of the feeder is shown in Fig.2. The information about the placement of the available devices in the system is demonstrated in Table I. The coefficients needed to solve the optimization are explained in Tables II and III. The value of coefficients have been extracted from references [11,12].

TABLE I
CURRENT CONDITION OF THE FEEDER

Device Type	NUMBER	Cost($)
RECLOSER	0	0
FUSE	7	3500
ISOLATOR	11	16500
BREAKER	4	13000
Fixed Cost	33000	
CENS	35430	
Total Cost	57342	

TABLE II
DEVICES COST

Device Type	Cost ($)
Recloser	1400
Sectionalizer	6500
Isolator	1500
Fuse	500

TABLE III
SUGGESTED PLACEMENT TO ALLOCATE DEVICES

Suggested Placement of Protective Devices	Suggested Placement of Switching Devices
11,16,28,48,58,105,119,121,128 ,131,152,160,178,157,159,36,45 ,54,56,124,127,129	117,103,54,51,45,36,14,2,179,15 6,159,143,137,183

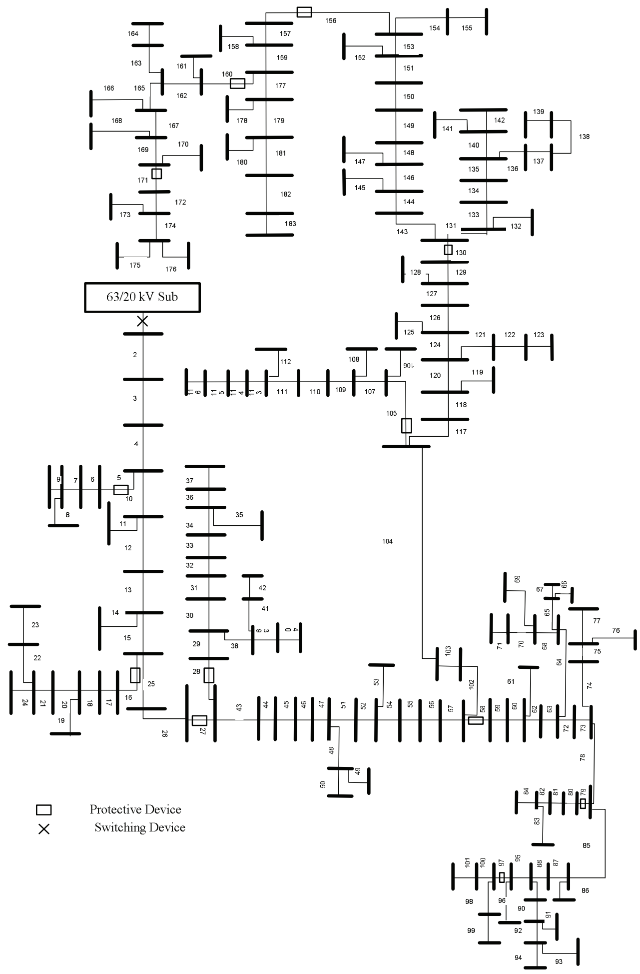

Figure 2: The single line diagram of the studied feeder

TABLE V
COMPONENT DATA FOR ANALYZED FEEDER

Number of branch	Installed load (kVA)	Length(m)	Permanent Failure rate (F/year)	Number of branch	Installed load (kVA)	Length(m)	Permanent Failure rate (F/year)	Number of branch	Installed load (kVA)	Length(m)	Permanent Failure rate (F/year)	Number of branch	Installed load (kVA)	Length(m)	Permanent Failure rate (F/year)	Number of branch	Installed load (kVA)	Length(m)	Permanent Failure rate (F/year)
1	0	80	0.016	38	0	250	0.05	75	0	20	0.004	112	100	15	0.003	149	0	200	0.04
2	0	50	0.01	39	0	50	0.01	76	200	250	0.05	113	100	140	0.028	150	200	240	0.048
3	50	400	0.08	40	0	350	0.07	77	160	240	0.048	114	200	230	0.046	151	0	330	0.066
4	0	500	0.1	41	0	360	0.072	78	0	120	0.024	115	0	10	0.002	152	200	1600	0.32
5	250	50	0.01	42	0	100	0.02	79	100	240	0.048	116	0	50	0.01	153	0	250	0.05
6	0	400	0.08	43	425	140	0.028	80	315	160	0.032	117	100	120	0.024	154	200	150	0.03
7	0	100	0.02	44	0	10	0.002	81	200	120	0.024	118	0	10	0.002	155	315	250	0.05
8	200	200	0.04	45	0	40	0.008	82	0	380	0.076	119	25	350	0.07	156	100	60	0.012
9	315	80	0.016	46	0	40	0.008	83	100	15	0.003	120	0	370	0.074	157	0	180	0.036
10	0	230	0.046	47	0	500	0.1	84	25	70	0.014	121	0	360	0.072	158	50	150	0.03
11	100	210	0.042	48	0	630	0.126	85	200	300	0.06	122	0	40	0.008	159	0	400	0.08
12	25	400	0.08	49	50	10	0.002	86	0	140	0.028	123	0	30	0.006	160	0	500	0.1
13	0	1050	0.21	50	200	600	0.12	87	200	10	0.002	124	0	50	0.01	161	100	10	0.002
14	0	20	0.004	51	200	10	0.002	88	100	330	0.066	125	200	150	0.03	162	0	900	0.18
15	0	20	0.004	52	0	130	0.026	89	0	140	0.028	126	100	310	0.062	163	0	60	0.012
16	50	300	0.06	53	200	15	0.003	90	250	550	0.11	127	0	200	0.04	164	200	850	0.17
17	0	40	0.008	54	500	100	0.02	91	0	5	0.001	128	100	300	0.06	165	0	70	0.014
18	0	370	0.074	55	250	60	0.012	92	200	570	0.114	129	500	150	0.03	166	0	30	0.006
19	50	15	0.003	56	200	450	0.09	93	0	1000	0.2	130	0	120	0.024	167	0	450	0.09
20	200	100	0.02	57	0	190	0.038	94	0	30	0.006	131	0	130	0.026	168	50	450	0.09
21	0	10	0.002	58	250	350	0.07	95	50	500	0.1	132	100	10	0.002	169	0	150	0.03
22	0	30	0.006	59	0	180	0.036	96	0	350	0.07	133	100	400	0.08	170	50	50	0.01
23	0	30	0.006	60	0	180	0.036	97	50	100	0.02	134	160	420	0.084	171	50	200	0.04
24	0	100	0.02	61	500	350	0.07	98	315	50	0.01	135	0	60	0.012	172	0	120	0.024
25	200	50	0.01	62	100	50	0.01	99	315	300	0.06	136	0	150	0.03	173	100	210	0.042
26	100	210	0.042	63	0	160	0.032	100	200	300	0.06	137	0	150	0.03	174	200	260	0.052
27	0	420	0.084	64	0	350	0.07	101	50	630	0.126	138	200	120	0.024	175	50	300	0.06
28	315	80	0.016	65	100	50	0.01	102	0	10	0.002	139	200	120	0.024	176	0	200	0.04
29	0	150	0.03	66	0	15	0.003	103	0	50	0.01	140	0	220	0.044	177	0	30	0.006
30	100	420	0.084	67	100	180	0.036	104	0	60	0.012	141	100	10	0.002	178	100	250	0.05
31	160	450	0.09	68	200	360	0.072	105	0	50	0.01	142	0	220	0.044	179	0	15	0.003
32	100	10	0.002	69	100	420	0.084	106	100	15	0.003	143	0	40	0.008	180	100	8	0.0016
33	400	220	0.044	70	200	240	0.048	107	0	180	0.036	144	0	120	0.024	181	250	120	0.024
34	0	10	0.002	71	160	120	0.024	108	0	40	0.008	145	200	40	0.008	182	0	20	0.004
35	315	150	0.03	72	500	210	0.042	109	250	60	0.012	146	0	60	0.012	183	200	250	0.05
36	315	340	0.068	73	0	70	0.014	110	250	200	0.04	147	50	15	0.003	------	------	-------	-------
37	400	200	0.04	74	100	300	0.06	111	0	15	0.003	148	50	240	0.048	------	------	-------	-------

TABLE IV
OPTIMIZATION RESULTS

Device Type	NUMBER	Cost($)
Recloser	1	0
Fuse	33	3500
Isolator	16	16500
Fixed Cost		49000
CENS		2143.4
Total Cost		51143.4

V. CONCLUSION

In this paper, an objective function has been defined to find the optimum location, type and number of protective or switching devices in distribution systems. To calculate the reliability indices, new analytical method has developed. By this method, calculating CENS and other reliability indices is possible.

The proposed objective function has been optimized by genetic algorithm. To illustrate the advantages of the method, it is applied to an actual distribution system. The results clarify the effectiveness of the method

VI. APPENDIX

T: total number of customer in feeder

mb: number of sections of the main branch

λ_{mi} : Failure rate of the section (i) from the main branch

$\lambda(s,p)$: Failure rate of the section (p) from s^th^lateral branch

N_{mi} : Number of customers for section (j) from the main branch

$flb(i)$: First downstream lateral branch of section (i) from the main branch

$N(s,p)$: Number of customers for section (p) from the s^{th} lateral branch

$ts(s)$: Number of the sections from the s^{th} lateral branch

$blb(i)$: First upstream lateral branch of section (i) from the main branch

$fdmb(i)$: First downstream main branch for i^{th} lateral branch

$fumb(i)$: First upstream main branch for i^{th} lateral branch

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