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OPTIMIZED SWITCH ALLOCATION TO IMPROVE THE RESTORATION ENERGY IN DISTRIBUTION SYSTEMS

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In distribution networks switching devices play critical role in energy restoration and improving reliability indices. This paper presents a novel objective function to optimally allocate switches in electric power distribution systems. Identifying the optimized location of the switches is a nonlinear programming problem (NLP). In the proposed objective function a new auxiliary function is used to simplify the calculation of the objective function. The output of the auxiliary function is binary. The genetic algorithm (GA) optimization method is used to solve this optimization problem. The proposed method is applied to a real distribution network and the results reveal that the method is successful.

K e y w o r d s: Power distribution systems, switches, restoration energy, genetic algorithm (GA)

1 INTRODUCTION

The main objective of the planning and operation of electric power distribution systems is to satisfy the system load and energy requirements as economically as possible with a reasonable assurance of continuity and quality. The two aspects of relatively low cost electrical energy at a high level of reliability are often in direct conflict due to the fact that providing a higher level of reliability will cost utilities more in capital and operational expenditures. This has become justification to emphasize on the optimization of the system costs and reliability [1].

The optimal placement of the switches and the protective devices is one of the most important parameters in designing power distribution systems. Therefore, there is an increasing interest in optimization of allocation of protective and switching devices in distribution systems and there have been many studies in this regard [2–10]. References [6, 7, 11] propose different mathematical models and optimization methodologies for optimal placement of protective and switching devices. The objectives of the references are to increase the reliability and to decrease the costs. Several optimization methods have been used to solve such problems as genetic algorithm (GA), ant colony system (ACS), reactive tabu search (RTS), simulation annealing, *etc*[5–11].

In [9], the optimized placement of protective devices is used to decrease the system average interruption frequency index (SAIFI). Reference [6] Engages with the decreasing of the system cost to determine the optimal device position. The main difference between methods proposed in [11] and [6, 9] is using single or multi objective. Reference [11] has determined device placements in distribution system to improve SAIFI, SAIDI and total cost.

Most of the above approaches are mainly theoretical. It means that the application of the optimization results is not feasible for real feeders. In addition, in most of the above references the restoration effect and maneuver by other feeders are omitted. In this paper, the restoration effect is taken into account. The new mathematical model is introduced to calculate the restorative energy while a fault occurs. A new index is introduced to show the energy restoration of the customers called R.I (Restoration Index). A new objective function based on R.I has been developed. The genetic algorithm has been used to optimize the objective function. From the application of the method on a real distribution feeder, the best switch position can be found.

2 PROBLEM STATEMENT

It is an interesting subject to increase the reliability indices in distribution systems and decrease the system cost. Hence, researchers try to find suitable solutions obtain these goals. One method to increase the system reliability is finding the optimum placement of devices. Several studies have been carried out about this subject. But, there is not any analytical solution in most studies to optimize the placement of protective or switching devices in distribution systems. Proficiency on all sides of the problem can be achieved when analytical solution is developed for solution. When analytical method is used to solve the problem, method correction investigation is accessible and easy. Hence, new method is introduced in this paper to calculate the energy restoration in distribution systems whose calculation is analytical.

In recent researches concerning the optimization of the device placements, there seems to be two other problems related to the implementation of the optimum results in

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the system as well as the lack of confidence of the managers to the proposed changes. When results devise the system to change most of device placements, superintendents are reluctant to main changes in the system and do not risk. Most solutions proposed in recent researches emphasize the main changes. Therefore, a practical solution is proposed in this paper.

3 PROBLEM FORMULATION

By fault occurrence in distribution networks, several customers experience an interruption. But, with switching device, it can be possible to restore some of them. Although in references [6,7], the main subject is total cost and reliability index, there is brief pointing to energy restoration. The new model is developed to calculate the RI (restoration Index). In Mathematical model of the factors, there is the auxiliary function $A(i,j)$ which might be described as follows in (5). R.I is demonstrated as follows

$$RI = \sum_{i=1}^{3} factor(i)\,, \tag{1}$$

$$\begin{aligned} factor(1) = \sum_{i=1}^{mb} \boldsymbol{X}_{si} \Bigg(\sum_{j=1}^{mb} \lambda_{mj} A(i,j) \times \\ \sum_{k=1}^{blb(i)} \sum_{l=1}^{ts(k)} L(k,l) A(fdmb, i-1) \prod_{m=fdmb(k)}^{i-1} (1-\boldsymbol{X}_{sm}) + \\ \sum_{n=flb(1)-flb(i)+1}^{flb(1)} \sum_{p=1}^{ts(n)} \lambda(n,p) A(1, ts(n)) A(1, fumb(n)) \times \\ \sum_{q=1}^{blb(i)} \sum_{r=1}^{ts(q)} L(q,r) \prod_{t=fdmb(q)}^{i-1} (1-\boldsymbol{X}_{st}) A(fdmb(q), i-1) \Bigg), \end{aligned} \tag{2}$$

$$\begin{aligned} factor(2) = \sum_{i=1}^{mb} \boldsymbol{X}_{si} \Bigg(\sum_{j=1}^{mb} \lambda_{mj} A(i,j) \sum_{k=1}^{i-1} L_{mk} \times \\ A(k+1, i-1) \prod_{l=k+1}^{i-1} (1-\boldsymbol{X}_{si}) + \\ \sum_{n=flb(1)-flb(i)-1}^{flb(1)} \sum_{p=1}^{ts(n)} \lambda(n,p) A(1, ts(n)) \times \\ A(i, fumb(n)) \sum_{q=1}^{i-1} L_q \prod_{r=q+1}^{i-1} (1-\boldsymbol{X}_{sr}) A(1, i-1) \Bigg), \end{aligned} \tag{3}$$

$$\begin{aligned} factor(2) = \\ \sum_{i=1}^{mb} \boldsymbol{X}_{si} \Bigg(\Big\{ \sum_{k=1}^{blb(i)} \sum_{l=1}^{ts(k)} \lambda(k,l) A(1,l) + \sum_{w=1}^{i-1} \lambda_w \Big\} * A(1, \beta-1) \times \\ \Big\{ \sum_{n=flb(1)-flb(i)+1}^{flb(i)} \sum_{p=1}^{ts(n)} L(n,p) + \sum_{v=i+1}^{mb} L_{mv} \Big\} \Bigg), \end{aligned} \tag{4}$$

$$A(i,j) = \begin{cases} 1\,, & \text{if no protective objct in position } i \text{ to } j \\ 0\,, & \text{otherwise.} \end{cases} \tag{5}$$

The value of this function is a binary variable. If $A(i,j)$ equals (1), it means that there is no protective device between branches i and j. The meaning of zero value of $A(i,j)$ is the existence of the protective devices at least in one of the sections between branches i and j.

Factor (1) is related to the fraction of total restorative energy recover at lateral branches when a short circuit occurs in the sections of the main or the lateral branches. There are two main terms in this factor. One of them concerns with the lateral branches recovery loads when short circuit occurs at the sections of the main branch. The other is relevant to those loads which recovering when fault occurs at lateral branches. When $\boldsymbol{X}_i$ is (1), it means that one switching device is allocated at section I and the ability to recover the portion of interrupted customers.

Factor (2) is similar to factor (1). This factor however indicates the portion of the recovery energy installed in the lateral branches.

Factor (3) is of a different nature. It refers to the maneuver effect of the considering feeder by neighboring feeders. The maneuver between distribution feeders can increase the system reliability and reduce the interruption duration.

4 OPTIMIZATION OF THE OBJECTIVE FUNCTION

Good position to allocate switches in distribution systems relate to optimum value of RI The self-evident result of the optimization of RI is the switch allocation in each section of the main branch. To lead good solution to real optimum state, some constrains should be added. In (6) the objective function with constrains and additional terms are shown.

The additional term to the objective function corresponds to the penalty coefficient (M). This term leads the optimum result to the basic feasible solution in which the number of switches is minimized.

Maximization of energy restoration or the above objective function is a nonlinear programming problem. To solve this problem, intelligent solution technique is useful. Ref [5,11] use ant colony system as an optimizer. In [6,8] reactive tabu-search is used to solve the problem. Another optimization methods used in papers is genetic algorithms as proposed in [2,7,9]. In this paper, genetic algorithm is used to solve nonlinear programming for the maximization of the energy restoration in distribution systems.

Each chromosome used in genetic algorithm has (n) genes. (n) is equal to the number of sections of main feeder branch. Genes are binary variables. When the value of m^{th} gene is (1), there is a switching device in the m^{th} section of main branch. In Fig. 1 the typical chromosome is shown.

Table 1. Component data for analyzed feeder

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

Table 2. Additional considered assumptions and constraints for real life 183-bus feeder

Present position of devices	
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
Present value of objective function	368527
Neighboring feeders	
Ganjbakhsh(interconnected to section 9 of this feeder)	
Hamidieh(interconnected to section 14 of this feeder)	
Arababad(interconnected to section 183 of this feeder)	

0	0	1	0	1	....	0	0	1	0

Fig. 1. Scheme to represent typical chromosome in genetic algorithm

Table 3. Alternative solutions obtained with the implemented methodology

Proposed alternative solution	
Number of the proposed isolators	12
Positions of the isolators	9,14,183, 43,44,52,54, 104, 129,144,177,179
The optimum value of the objective function	608610
The optimum value of R.I	788610

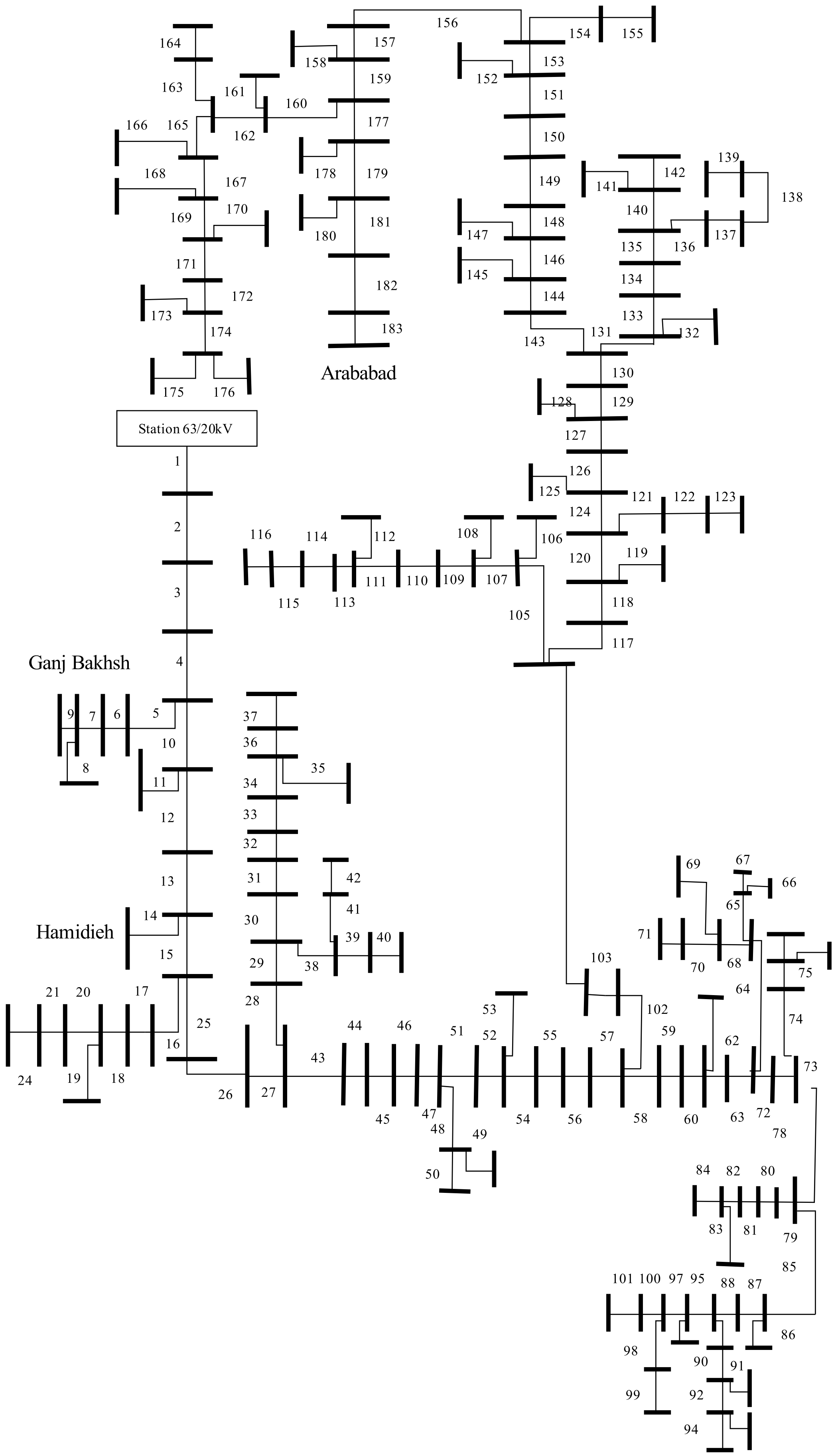

Fig. 2. 183-Bus real life distribution system

5 TESTS AND RESULTS

The actual development and tests are focused on the placement of the switching devices in the overhead radial distribution feeders.

The proposed technique has been applied to a 20 kV, real life 183-bus feeder. This feeder is a part of Karaj distribution network. It has two interconnection lines and two neighboring feeders. Permanent and temporary fault rates used in the test are 0.02 & 0.8 faults/(km year^{-1}) respectively. Component data for analyzed feeder is described in Table 1.

The considered assumptions and constraints for real life 183-bus feeder are as follows:

There is one circuit breaker between buses 1 and 2 (first section of the main branch). It is assumed that the neighbor feeders can feed total load of intentioned feeder. Since these feeders can feed total load of intentioned, this assumption is feasible. Therefore, there is no problem to provide the energy needed.

There are 7 fuses, 12 isolators and one recloser in this feeder. Recloser is allocated in the first branch and the positions of the fuses and isolators are given in Table 2.

There are three points to interconnect this feeder to its neighboring feeders. These points are demonstrated in Table 2.

Comparing the results obtained by the implemented methodology with those of the present condition presents the advantages of applying this method to the distribution feeders. The present feeder condition is presented in Table 2. The difference between the optimum value of the objective function and the value of the present feeder condition is 240083. This increase in energy restoration is achieved by the installation of 9 isolators in proper positions of the distribution feeder. Concerning the other aspect of the optimization, *ie* lowering the cost, is should be mentioned that, as confirmed by the Tables 2 and 3, the proposed method has lead to desired results and the costs have decreased.

6 CONCLUSION

This paper presents an optimization technique for the placement of switches in electric power distribution systems. R.I index has been introduced. This index is relevant to restorative energy in distribution systems when faults occur in distribution feeders. A novel mathematical method is developed to calculate the index. To simplify the calculations of the equations in R.I, an auxiliary function is used. By optimizing the R.I, optimal placement of the switches has been obtained. During the optimization process, to prevent the solution from evident conditions, the penalty factor (M) is used. This coefficient guides the best solution to minimize the number of switches required. GA (genetic algorithm) has been used to optimize the objective function. The method has been applied to a real distribution system and the obtained results illustrate the effectiveness of the proposed method.

Appendix

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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