International Journal on "Technical and Physical Problems of Engineering" (IJTPE)
Published by International Organization of IOTPE
ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

December 2014 | Issue 21 | Volume 6 | Number 4 | Pages 106-111

MULTI-OBJECTIVE MODELING FOR FAULT INDICATORS PLACEMENT USING OF NSGA II TO REDUCE OFF TIME AND COSTS IN DISTRIBUTION NETWORK

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Abstract - According to the reports of power companies, about 80-90% of the outages occurred in the network are due to the error in the distribution system. The occurrence of these outages leads to the customer dissatisfaction and the lack of energy sales and significant economic losses in the distribution companies. Thus increasing network reliability to reduce these losses has attracted the attention of many experts. In this paper, fault indicator placement is performed using multi-objective function. Creating high reliability and reducing costs are the main goals of this paper and for this purpose multi-goal objective function is used. Fault indicator placement caused a plan with respect to all conditions governing the issue. Optimization of this problem, especially for large networks is a complex and difficult task. In this paper, NSGA II algorithm is used for optimization.

Keywords: Optimal Placement, Fault Indicator, Reliability, NSGA II Algorithm, Distribution Network.

I. INTRODUCTION

Due to increasing use of electric energy and the growing demand as the main energy of industry, higher reliability by minimizing the time of outages is necessary. Meanwhile, distribution networks play an important role in increasing the effectiveness of power networks due to their extent. Socioeconomic effects of increased non-distributed energy in this sector are indispensable. Non distributed energy rate reduction in distribution sector is an important factor in the success of the distribution companies and hence in the operation of distribution networks it is essential to act in such a way that the least amount of load is out of the circuit due to the fault and the spent costs for load recovery would be reasonable.

In [9], Falaqi et al studied the effect of fault indicators on the reliability index of distribution network and after describing the model and the methods required to evaluate the reliability of distribution networks in the presence of fault indicators, used the proposed model on a real network in Iran with the assumption of constant place for fault indicators.

In [16], Suazo et al investigated the effective placement of fault indicators to improve the reliability and quality of power supplied to subscribers using fuzzy logic. In [6] different methods were studied to detect errors in transmission and distribution networks, and the advantages and disadvantages of each method in error detection are compared. In [4] the effect of fault indicator placement on non- distributed energy and the outage costs have been investigated using genetic algorithms.

In [10], the optimal placement of fault indicators using an artificial immune algorithm has been evaluated and the total costs of reliability in terms of key customers have been evaluated using vaccination in the immune algorithm. Reference [15] presents the multi-objective optimization methods for optimal placement of switches and protective devices in distribution networks. Ant colony optimization algorithm has been implemented as multi objectives on this issue to minimize the total cost and the minimization of SAIFI and SAIDI reliability indices.

In [5], a feeder optimization method or an entire network is possible with less computation. In this reference in order to avoid the exponential increase in the amount of computation due to an increase in the size of the network, a special decomposition method is used to separate the network into smaller networks. Reference [11] shows the importance of optimal placement of protective equipments and the distributed generation units on radial feeders in ensuring the reliability of the distribution network. Distributed generation units have been presented as one of the options to improve the reliability of the distribution network.

Reference [12] offers a new method for the placement of protection and control equipments in radial distribution feeders based on tabu search algorithm. Reference [17] presents the non-dominated sorting genetic algorithm II (NSGA II) to solve the power recovery problem in the distribution network. Due to the large number of conflicting objective functions, the operations of power recovering is multi-objective and the optimization problem have multiple constraints.

To increase economic productivity of distribution network's automation systems, reference [3] offers the immunization algorithm for the placement of switch to reduce the total cost of the service outages and the cost of investment in line switches.

This paper presents a model to determine the number and location of the fault indicators in the distribution network in which a multi-objective algorithm based on efficient response space is used for the optimization of the problem. Improvement of reliability and the lowest cost of constructing the secsioners, maneuver switches, and fault indicators are the main goals of optimization.

II. FORMULATION

A. The Objective Function

In the proposed multi-objective modeling, in order to locate the fault indicators in the distribution system, the objective function is [1]:

$$f_{Total} = \min\{F_c \ , F_{EENS}\} \tag{1}$$

where, F_c is The cost objective function and F_{EENS} is the objective function of the lost energy.

B. The Cost Objective Function [3]

$$F_c = \min\{IC_{fi} + OC\} \tag{2}$$

where, IC_{fi} is the construction cost of fault indicators and OC is maintenance costs of equipments, which each of them is defined as follows.

C. The Construction Cost of Fault Indicators [3]

$$IC_{fi} = \sum_{i=1}^{N_f} \gamma(i).C_f i \tag{3}$$

where, $\gamma(i)$ is presence or absence of indicator in ith candidate location which is zero or one, C_{fi} is the construction cost of each indicator and N_f is number of candidate locations for fault indicators.

D. Maintenance Costs of Equipment

This cost is equal to 20% of the cost of constructing equipment, and the present value is calculated from Equation (4).

$$OC = \sum_{t=1}^{N_y} (f_{pw})^t \times (0.2 \times \{IC_{fi}\}) \tag{4}$$

$$f_{PW} = \frac{1+infr}{1+intr} \tag{5}$$

where, N_y is planning year, $infr$ is the annual inflation rate and $intr$ is the annual interest rate.

E. Function of the Lack of Power or the Lost Energy

To obtain the lost energy, Equation (6) is used, which consists of three parts. The first part includes the lost energy during fault detection and switching time and the second part includes the lost energy for those loads that are off after switching till the end of the repair period [1].

$$F_{EENS} = \sum_{i=1}^{N_s} L_i.\lambda_i [\sum_{j=1}^{N_{sw}} P_j.T_{sw}(i) + \sum_{j=1}^{N_{rp}} P_j.T_{rp}] \tag{6}$$

where, N_s is the number of Feeder branch, λ_i is the annual rate of fault occurrence in ith branch of feeder, L_i is length of ith line (km), $T_{sw}(i)$ is time of fault detection and switching, $T_{rp}(i)$ is line repair time, N_{sw} is the number of switched off loads in the event of an error and N_{rp} is the number of switched off loads after switching that have not been restored.

F. Error Detection and Switching Time

Using the fault detectors and according to their locations in the network, the feeder is divided into several sections. Since the time of locating fault in a section is less than the entire feeder, so the fault locating is done faster. In this case, the fault locating time is calculated using Equation (7) [4].

$$T_{sw}(i) = T_0.[L_i / \sum_{j=1}^{N_s} L_j] \tag{7}$$

where, T_0 is time required for the fault locating on the feeder without fault detectors and L_i is length of ith line (km).

G. Coding of Decision Variables

The proposed chromosome structure contains substring as Figure 1 that is the number of candidate locations of fault indicators. Each of the chromosomes is as zero or one.

N_{fl}

fl_1	fl_2	…	fl_{34}

Figure 1. The proposed chromosome structure

H. NSGA Based Optimization [18]

Since the genetic algorithm searches the solution space from several points in parallel, it can be used desirably for finding a subset of effective responses. NSGA is an edition of a genetic algorithm for solving optimization problems with multiple criteria.

III. COMPUTATIONAL STAGES OF ALGORITHM

NSGA general steps for solving optimization problems in distributed systems are as follows.

1. The initial population
2. Intersection
3. Mutation
4. Evaluation of objective functions
5. Ranking the population based on the concept of non-recessive
6. Density estimation

At this point, the components that are in a non-recessive place are ranked according to the following criteria [18].

$$cd\left(X_1\right) = \prod_{j=1}^{k} cd\left(X_i\right) \tag{8}$$

$$cd_j\left(X_i\right) = \left| \frac{f_i\left(X_{i+1}\right) - f_i\left(X_{i-1}\right)}{f_j^{\max} - f_j^{\min}} \right|, \quad i \in S^r \tag{9}$$

where, $cd_j(X_i)$ value shows the distance of the *i*th member to the closest member at level S^r according to the *j*th objective function. The difference between the values $f_j^{\min}$ and $f_j^{\max}$ in the Equation (9) shows the range of the objective function changes *fj*.

- *Selection*: The proposed method is based on competition and is performed in the following steps:

Step 1: Selecting Two members randomly from the population.

Step 2: Comparison of two selected members according to the non-recessive level r and density index cd, so that if non-recessive level of the two members is different, the member that has lower non-recessive level, will be superior and if both members are in the same level, the member with lower density index will be superior.

Step 3: The superior member will be stored in the list of members of the new generation.

Step 4: The above steps are repeated as the number of members required for the new generation.

- *Stop*: Algorithm stop criterion can be the repetition or a specified number or any other appropriate measures.

IV. DECISION TO CHOOSE THE FINAL ANSWER

After a set of efficient solutions were obtained using NSGA, the designer should choose the final answer of the problem among the members of this set according to technical prioritizations and satisfaction rate of objective functions. In this paper the max-min method is used to choose the best solution of the multi-objective problem using the following problem [18].

$$\max\left\{\min_{k}\left[\left(\frac{f_{C\max}-R\left(\tilde{f}_{CK}\right)}{f_{C\max}-f_{C\min}},\ \frac{f_{EENS\max}-f_{EENSk}}{f_{EENS\max}-F_{EENS\min}}\right)\right]\right\} \quad (10)$$

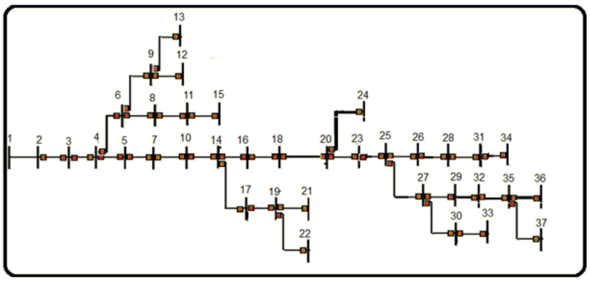
V. NUMERICAL STUDIES

In this paper, optimal placement of fault detectors is modeled as a multi-objective problem. The objective functions are: 1) General objective function that includes all fixed and variable costs. 2) Objective function related to the energy not supplied. The main goals of the plan are increasing system reliability level and reducing the cost of fault indicators.

In order to evaluate the proposed model and algorithm performance and efficiency of the proposed method, some studies have been performed on a real network. In this regard, the effect of adding each of the devices on the network are examined by performing various experiments on the sample network.

VI. THE UNDER STUDY NETWORK

The investigated radial network is shown in Figure 2 which includes 37 buses and 72 candidate locations for fault detectors (fault indicators and secsioners can be built at the beginning and end of each line). Data of this network is given at Table 1. There are three load types in this network (agricultural, domestic, and industrial) which each of them has a different average outage cost (Table 2). Other data is given in the Appendix.



set of candidate locations to install fault indicators

Figure 2. Part of the actual distribution network of Ardabil, Iran

Table 1. General data of the studied network

installation cost of each indicator ($)	25000000
time required to determine the location of fault and switching (hours)	1
time required to repairing (hours)	5
Failure rate per kilometer of lines (f/y)	1.49
planning horizon (year)	5
maintenance cost ($)	20% of Investment
average cost of domestic loads ($)	500
average cost of agricultural loads ($)	650
average cost of industrial loads ($)	850
annual inflation	0.16
annual interest rate	0.2

Table 2. The results for experiment 1

Option	Value
normalized value of the energy not supplied	1
normalized value of equipment cost	0
cost of the energy not supplied	6890240000
cost of equipment	0

It should be noted that the average cost of the energy not supplied for agricultural, domestic, and industrial loads are 850 $/KWh, 1300$ /KWh and 1700 $/KWh, respectively.

To demonstrate the efficiency of the model presented in this paper, we perform two experiments on the sample network and in these experiments, the effect of adding each of the devices on different parts of the objective function will be considered and compared. The experiments are explained in detail in the following.

In the 1st experiment which is the base case, the objective function values obtained ignoring all of the equipment. In the 2nd experiment, optimal placement of fault indicators is performed and the objective function values is calculated per each of average cost of not supplied energies.

Table 3 shows the required time to detect fault and switching for experiment 2 and the results for various experiments are given in the subsequent tables. Two NSGA II and OMOPSO methods are employed in the second test to optimize the problem and the results are comprised at Table 4. As it is seen from Table 4, the NSGA II algorithm provides the best solution.

Numerical results corresponding to the best solutions calculated by the max-min method are presented in Table 4 for different parts of the objective function. As it is seen from Table 4, the amount of the energy not supplied is reduced by increasing the number of fault indicators.

Table 3. Time required to detect fault and switching after determination of fault indicators in experiment 2

section no	fault locating time	section no	fault locating time	section no	fault locating time
1	0.1455	13	0.1383	25	0.122
2	0.1455	14	0.1627	26	0.1101
3	0.1455	15	0.1383	27	0.1003
4	0.1455	16	0.0801	28	0.1101
5	0.1627	17	0.1383	29	0.1101
6	0.1455	18	0.0801	30	0.1003
7	0.1627	19	0.122	31	0.141
8	0.1627	20	0.0801	32	0.1101
9	0.1455	21	0.0801	33	0.1003
10	0.1627	22	0.122	34	0.141
11	0.1627	23	0.122	35	0.141
12	0.1627	24	0.122	36	0.141

Table 4. The results for experiment 2

option	value	
	OMOPSO	NSGA II
location of installed indicators	4,10,16,18,23,26,30	4,12,15,18,25,26,30
cost of installed indicators	175000000	175000000
cost of system maintenance	15825860	15825860
normalized value of the energy not supplied	0.814366	0.7993678
normalized value of equipment cost	0.8125	0.8125
cost of the energy not supplied	6955261000	6827071000
cost of equipment	1908259000	1908259000

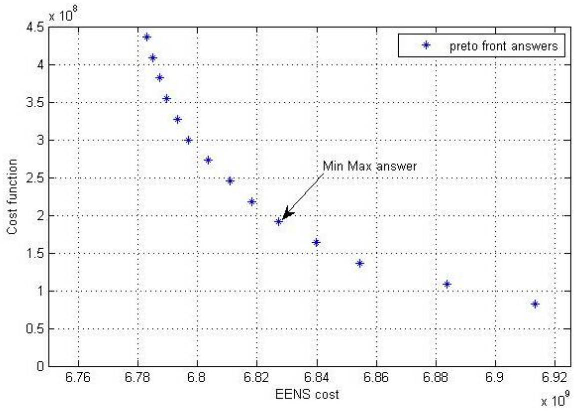


Figure 3. Efficient solutions space derived from experiment 2 by NSGA II

On the other hand, an interactive should be exist between the energy not supplied and the total cost (because the total cost increases when the number of fault indicators increase). On the other hand, it is seen from table 4 that when the number of fault indicators increases, the required time for fault locating decreases. Also, the pareto front of the problem which is obtained from solving the problem by NSGA II, and the selected answer through max-min method are illustrated in Figure 3.

As it is seen from Figure 4, the best answer is obtained for experiment 2. Comparison of changes in the system reliability indices (SAIDI, CAIDI, SAIFI, EENS) due to installation of various equipment in the experiments is showed in the Figures 5-7.

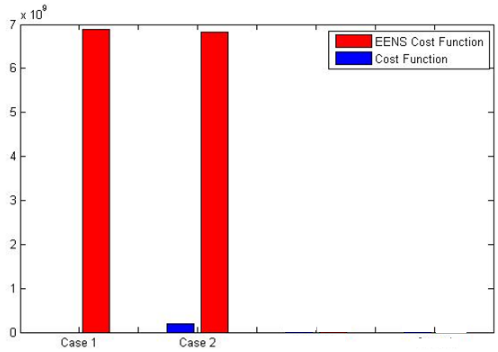


Figure 4. Comparison of results obtained by NSGA II for various experiments

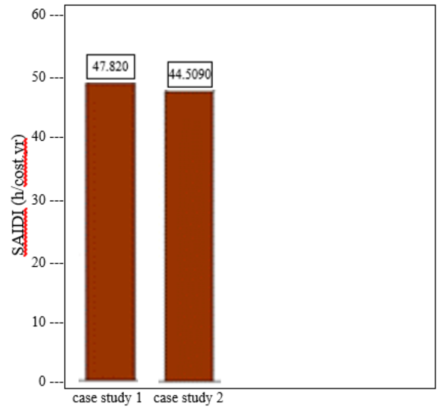


Figure 5. SAIDI results for various experiments

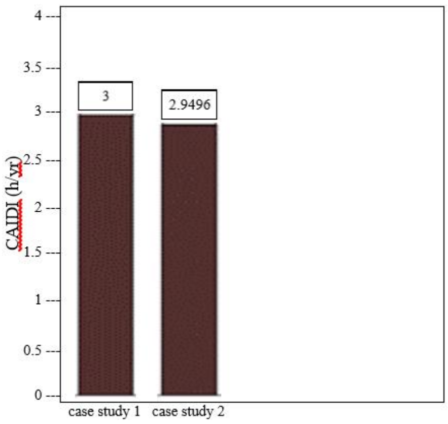


Figure 6. CAIDI results for various experiments

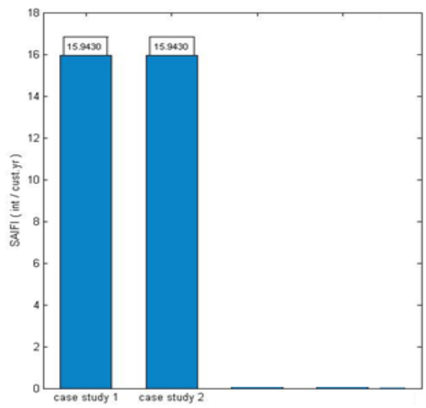


Figure 7. SAIFI results for various experiments

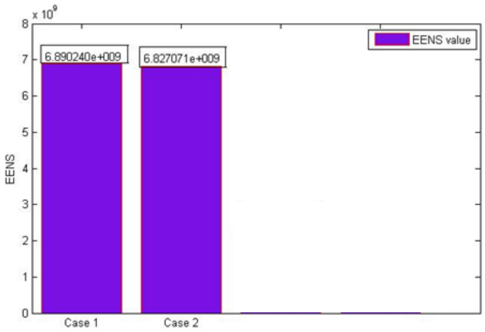


Figure 8. EENS results for various experiments

The comparison of obtained results shows that SAIDI of the system is highly related to number and location of installed equipment. This indicates that the rate of improvement in system reliability is obtained from installing equipment in the system.

It can be seen from the results that the best improvement in system reliability is obtained in the 2nd experiment. As it is seen from figures, CAIDI and EENS of the system is also changed that the reason is that the fault occurrence rate is constant. So, CAIDI is only the function of SAIDI, and because feeder loads are assumed to be constant in this study, so EENS is related only to system outage time.

VII. CONCLUSIONS

Fault indicators greatly reduce the required time for locating fault location. So, determination their optimal number and location could severely affect the reliability of the system. NSGA II is used in this paper for locating optimal location of the indicators and by studying various experiments, the impact of each equipment on cost function and system reliability indices is considered and compared. The obtained results provide good insight into the selection process. Also, this study showed that instead of one solution, a set of solutions can be achieved by modeling the problem as a multi-objective problem using NSGA II, that this provides a thorough viewpoint for system designers.

APPENDIX

Table 5. Capacity of loads of the sample system and their types

Bus number	load type	Predicted load	Bus number	load type	Predicted load
2	domestic	69	20	industrial	126.25
3	agricultural	57.5	21	domestic	86.25
4	domestic	34.5	22	agricultural	46
5	domestic	69	23	domestic	120.75
6	industrial	138	24	domestic	80.5
7	domestic	40.25	25	industrial	86.25
8	domestic	46	26	domestic	46
9	industrial	287.5	27	domestic	97.75
10	domestic	83.95	28	domestic	124.2
11	domestic	143.75	29	industrial	86.25
12	domestic	44.85	30	domestic	92
13	agricultural	86.25	31	agricultural	103.5
14	agricultural	46	32	agricultural	193.2
15	agricultural	80.5	33	domestic	132.25
16	domestic	103.5	34	industrial	138
17	agricultural	46	35	industrial	212.75
18	agricultural	57.5	36	industrial	155.25
19	domestic	86.25	37	agricultural	181.7

Table 6. Network sections data

line number	beginning and end bus of section	section length (Km)	line no.	beginning and end bus of section	section length (Km)
1	1, 2	0.95	19	18, 20	0.7
2	2, 3	0.76	20	19, 21	0.9
3	3, 4	1.2	21	19, 22	0.42
4	4, 5	1.6	22	20, 23	0.92
5	4, 6	0.87	23	20, 24	1.16
6	5, 7	0.67	24	23, 25	1.25
7	6, 8	1	25	25, 26	1.42
8	6, 9	1.35	26	25, 27	0.79
9	7, 10	1.32	27	26, 28	0.94
10	8, 11	1.09	28	27, 29	1.5
11	9, 12	0.43	29	27, 30	1.31
12	9, 13	1.43	30	28, 31	1.86
13	10, 14	4.5	31	29, 32	1.42
14	11, 15	1.1	32	30, 33	1.32
15	14, 16	1.34	33	31, 34	1.68
16	14, 17	0.56	34	32, 35	1.656
17	16, 18	0.34	35	35, 36	1.78
18	17, 19	1.7	36	36, 37	1.45

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