Fault Indicator Allocation in Power Distribution Network for Improving Reliability and Fault Section Estimation

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Abstract: Fault indicator (FI) is used in impedance-based methods for improving fault section estimation in power distribution feeders. The location and number of FIs affects on the reliability indices and can extra charge the distribution companies and consumers. In this paper, the optimal location and number of fault indicator (FI) are determined in Power Distribution Network (PDN) with special economical combined objective function. In this objective function, four imposed costs on distribution companies and consumers are taken into account. For solving this problem, a powerful method i.e. Multi-Objective Genetic Algorithm (MOGA) is used. Then the proposed method is tested on the two case studies, which one of them is a real distribution feeder of Bushehr power distribution company in Iran. At the end the results are presented discussed.

Keywords: Distribution system, Fault location, Fault Indicator

1 Introduction

Most of the researches presented so far in the field of fault location are focused on the fault location on the transmission lines; however, these algorithms are not suitable for locating the fault on the distribution networks. Since distribution systems are usually unbalanced nature such that mixed single phase and three phase laterals, non-homogeneous feeders, non-homogeneous phase conductor and unbalanced loading. These features can create some problems in fault location algorithm and also in fault section estimation, from which the multiple-estimation problem is the most important [1,2,3].

Based on a presented report, about 80% of interruptions are caused by faults in distribution networks [4]. PDN is susceptible to faults caused by different reasons such as:

- These networks are distributed in different regions (urban, residential, and concentrated in urban marginal areas) which are available for people.
- weather conditions
- equipment failure

These faults cause to decrease power quality, destroyed reliability indices, decrease benefits, and satisfaction of consumers from distribution companies. Therefore, this is favorable for consumers, if location of fault is found quickly and repaired them, consequently time of restoration is reduced.

Different methods are presented for fault location in PDN. These methods have two stages. In the first stage, the fault distance is determined and in the second stage, the fault section is estimated. Fault location methods are classified into two categories:

a) Impedance based methods [2,3]

b) Traveling wave based methods [5]

In the impedance based methods fundamental of voltage and current signals at the beginning of feeder are used. Implementation of these methods is very simple are cheap, but they have some problems such as sensitivity to fault resistance and multiple-solution [1, 4]. Traveling-wave methods consider the voltage and current waves, traveling at the speed of light from the fault towards the line terminals [5]. These methods are considered as very accurate, however, also as complex and costly for application, as requiring high sampling frequency [6, 7], Multi response and Detecting travelling wave in faults near to the fault location devices and in zero domain of voltage or current are difficult.

With this fault location review, the most methods need to estimate Faulted section. Fault section estimation can classified to three methods, using current pattern recognition, intelligent methods, different methods which have communications devices. These methods have different problems such as:

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- Many indices are presented but are not unique.
- Some of methods need to communication device and addition equipments. Consequently, they are expensive and complex.
- The most of methods need to data bank, which make of it and update of it is very difficult.
- …

With these notes, choice of method for locating fault depends on both system topology and available instrumentation for system monitoring.

Fault Indicators (FI) allocation can improve impedance based methods. Because of, it can speed up finding correct position of fault section estimation or reduce multi section estimation, consequently restoration time is reduced [8, 9]. Important questions are mentioned in below for FI:

- How many FIs does each feeder need?
- Which place do the designers prefer to install it?

At the first FI is presented in [2] but this paper did not present any special method for finding number and position of FIs. In continue different methods are presented for solving it such as GA (Genetic Algorithm), CBGA (Chu-Beasley Genetic Algorithm) and IM (Immune Algorithm). GA method, which is presented in [10], is used for solving the OFP problem. It finds the optimal place of FIs. Ref [11] analyzed the effect of FIs on reliability indices of PDN and the presented method in [11] is tested on real Iranian PDN. CBGA is used for optimal FI location in PDN [8]. This method extends the presented method in [12] and presents an objective function which is combined of the number of suspected locations and the distance among suspected locations. Also it uses the FI statuses for helping to find faulted section. IM is used for FIs optimal placement which is presented in [9]. It is presented a combined objective functions. The presented objective functions are combination cost of different types of loads (residential, commercial, industrial and key customers).

This paper presents optimal fault indictors allocation for fixed number and variable number of them in PDN with multi objective genetic algorithm. In this paper anew combined objective function is presented. These objective function is formed to four necessary function. In each objective function element, cost of different level and types of loads has been assumed. The special feature of this presented objective function is assuming forced cost on consumers and distribution companies besides of assuming previous presented objective function which is presented in different Refs on this topic. So in continue, both of them are combined and effect of optimal FI allocation is shown and compared with different methods which are presented till now. Therefore, at the end, the presented method is tested on feeder of Bandargah of Bushehr PDN in Iran.

The rest of this paper is organized as followsin Section 2 the proposed method is described and in Section 3 the multi objective optimization is described Simulation results of proposed method in different conditions are presented in Section 4. At the end conclusions are drawn.

2 Proposed Method

The security and reliability and service continuity of power distribution system is very important, but it is violating with occurring faults. Fast clearing and isolation of different faults types are critical in maintaining a reliable power system operation and improve service continuity indexes**.**
The proposed method presents a new optimal FI allocation method in PDN. In this method, anew combined economic objective function is assumed which must be optimized. Suggestion objective function is combination of three main part of benefit and disadvantage of finance such that show correct behavior of mutual effect between consumer and distribution companies. This objective function is composed four cases as follows:

- Energy not Supply (ENS) cost
- Operation cost and restoration cost
- Unsatisfied consumers cost
- FI cost (buying & installing)

2-1 Energy Not Supply (ENS) cost

In each interruption, restoration time depends to type of fault and its location. This cause to be created addition cost which is forced on Power distribution companies. It is Energy not supply which is introduced by (1):

$$C1 = c_i \sum_{i=1}^{n} P_i \, t_i \quad (1)$$

P_i: Amount of load ith
t_i: Interruption time of load ith
n: Number of section
c_i: cost of each kWh

2-2 Operation cost and restoration cost

Operation cost and restoration cost are divided to two parts as follows:

- The cost of engineer, employer and worker who work to restore the feeder.
- Needed equipments for restoration.

These parts are introduced by (2):

$$C2 = \sum_{i=1}^{n} \lambda_i l_i m_i co_i t_i + \sum_{i=1}^{n} m_i k_i t_i + F \quad (2)$$

λ_i: Interruption rate per year.
l_i: Length of segment ith.
m_i: Employer number.
co_i: Hourly cost of each worker.
t_i: Restoration time of segment ith.
k_i: Hourly cost of operation car.
F: cost of needed equipment for restoration.
n: Number of segment.

2-3 Unsatisfied consumers cost

When any interruption is occurred for each consumer, cause to they will be worry. Consequently the electrical distribution company must be compensating effect of this interruption for each consumer. It has a standard fine cost for each hour for each consumer. Unsatisfied cost is introduced in (3):

$$C3 = \sum_{j=1}^{m} \lambda_i l_i p_i cf_i t_i \quad (3)$$

λ_i: Interruption rate
l_i: Length of segment ith
p_i: Active power consumption of each consumer
cf_i: Hourly fine cost of each consumer
t_i: Restoration time of segment ith
m: Consumer number
n: Number of section

2-4 FI cost (buying & installing)

GA gives number and place of FIs in PDN as output. Number of FIs has some cost such as purchasing cost, installing cost and its effect on operation and repaired group. It is defined by (4):

$$C_4 = FIcost = buying\ and\ instaling\ c\ldots + repaired\ group\ cost \quad (4)$$

Now, these four objective functions must be optimized by one method of multi objective optimization.

3 Multi Objective Optimization

In mathematical terms, the multi objective problem can be written as:

$$\begin{aligned} &\min_x \, [\mu_1(x), \mu_2(x), \ldots, \mu_n(x)]^T \\ &\text{s.t.} \\ &g(x) \le 0 \\ &h(x) = 0 \\ &x_l \le x \le x_u \end{aligned} \quad (5)$$

where μ_i is the i-th objective function, g and h are the inequality and equality constraints, respectively, and x is the vector of optimization or decision variables. The solution of the above problem is a set of Pareto points. Thus, instead of being a unique solution to the problem, the solution to a multi objective problem is a possibly infinite set of Pareto points.

A design point in objective space μ^* is termed Pareto optimal if there does not exist another feasible design objective vector μ such that $\mu_i \le \mu_i^*$ for all $i \in \{1, 2, \ldots, n\}$, and $\mu_j < \mu_j^*$ for at least one index of j, $j \in \{1, 2, \ldots, n\}$.

3-1 Solution method

There exist many methods to finding a solution to a multi objective optimization problem, some of which are mentioned below:

- Constructing a single aggregate objective function (AOF) [13]
- The NBI, NC, SPO and DSD methods [14]
- Evolutionary algorithms [15]
- Other methods [16, 17] such as:

  - Multi objective Optimization using Evolutionary Algorithms (MOEA)
  - PGEN (Pareto surface generation for convex multi objective instances)
  - IOSO (Indirect Optimization on the basis of Self-Organization)

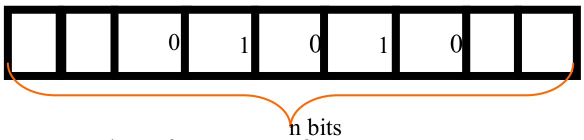
Among of these methods, MOGA is selected for optimizing, and in different methods of MOGA, weighted sum approach is selected. MOGA stages are explained in as follows:

3-2 Multi Objective Genetic Algorithm (MOGA)

3-2-1- Initial population

Initially many individual solutions are randomly generated to form an initial population. The population size depends on the nature of the problem, but typically contains several hundreds or thousands of possible solutions. Traditionally, the population is generated randomly, covering the entire range of possible solutions (the *search space*). Occasionally, the solutions may be "seeded" in areas where optimal solutions are likely to be found.

In this stage network data is inputted. Now n bits (0, 1) have assumed for allocating of FIs with attention to fitness function:



n: number of segments of PDN

Figure 1. Genes of FI allocations

Genetic generate randomize genes. The network calculation is doing with assumed these genes. If the value of bit ith is 1, this means segment ith has FI else this segment does not have and it do not came to network calculation.

3-2-2- Fitness function

BGAs are essentially un constrained search procedures within a given represented space where the search is guided according to a fitness function. In this paper the fitness functions and the penalty function is:

$$\min Z = w_1 C_1 + w_2 C_2 + w_3 C_3 + w_4 C_4 \quad (6)$$

That C_1, C_2, C_3 and C_4 are defined in section 2-1.

The strings are stored according to their fitness which is then ranked accordingly. The roulette wheel selection scheme is used for selecting the individuals for reproduction.

3-2-3 Genetic operators

Genetic operators are the stochastic transition rules applied to each chromosome during each generation procedure to generate a new improved population from an old one. A genetic algorithm usually consists of reproduction, crossover and mutation operators.

• **Reproduction**

Reproduction is a probabilistic process for selecting two parent strings from the population of strings on the basis of “roulette-wheel” mechanism, using their fitness values. This ensures that the expected number of times a string is selected is proportional to its fitness relative to the rest of the population. Therefore, strings with higher fitness values have a higher probability of contributing offspring.

• **Crossover**

Crossover is the process of selecting a random position in the string and swapping the characters either left or right of this point with another similarly partitioned string. This random position is called the crossover point. In this paper the characters to the right of a crossover point are swapped. The probability of parent-chromosomes crossover is assumed to be 0.7.

• **Mutation**

Mutation is the process of random modification of a string position by changing “0” to “1” or vice versa, with a small probability. It prevents complete loss of genetic material through reproduction and crossover by ensuring that the probability of searching any region in the problem space is never zero. In this paper the probability of mutation is assumed to be between 0.01 and 0.1.

3-2-4 Region division

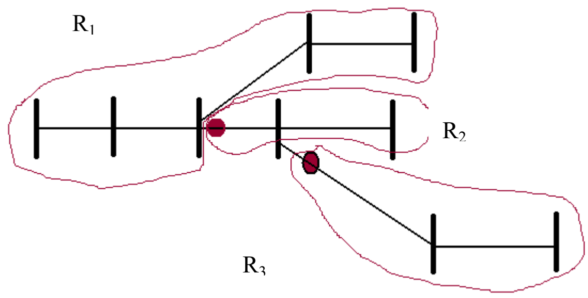
When Location of FIs is determined by MOGA then different regions should be defined. Region is a section of distribution feeder which is one of following conditions:

a- Section between two FIs

b- Section between one FI and end buses

c- Section between the beginning of feeder and the first FI

Figure 2 shows the different defined regions. In this figure three regions are defined R_1 till R_3.



fault indicator

Figure 2. Different defined regions

With this FIs and Defined Regions restoration time of each region is decreased and is calculated by (7):

$$T_i = T_{0i}\left(\frac{l_i}{\sum_{j=1}^{n} l_j}\right) \quad (7)$$

Which:

l_i: Length of region ith

T_i: Restoration time of region ith after FI allocation

T_{0i}: Restoration time of region ith before FI allocation

4 Application and simulation results of MOGA

Proposed method is tested on two distribution feeders which one of them is 13-bus IEEE test system and other one is a real feeder in Bushehr distribution network which is named Bandargah feeder. The following parameters are used in the present research are:

Population Size =20

Maximum number of generation =100

Probability of mutation = 0.05

Probability of crossover = 0.7

4-1 Test system 1: IEEE 13-BUS system

Single line of IEEE 13-bus is shown in Figure 3. Nine bits are selected for population length which is candidate for FI position. With applying the proposed method, the optimum number FI is two and the FI position is selected 671-684, 632-645. In this task FI location is done which its result is shown in Table1.

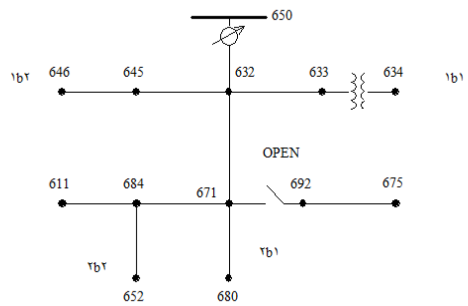


Figure 3. IEEE 13-bus test feeder

Table 1: Result of FI allocating in test feeder 13- bus IEEE

	Optimal place
1	671-684
2	671-684 & 632-645
Optimal number	2

4-2 Test system 2: Bandargah feeder

Bandargah feeder is one feeder of Bushehr distribution network in Iran. Its single line diagram is shown in Figure 4. Length of this feeder is 25 km with three laterals and five load taps. The additional information about this feeder is shown in Table 3 in Appendix. The result of optimal allocation with limited and unlimited number of FIs is shown in Table 2.

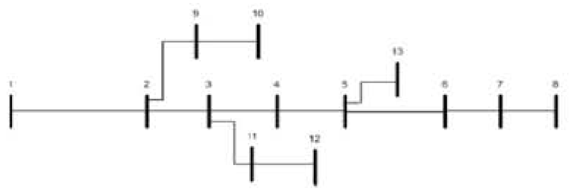


Figure 4. Bandargah feeder

Table 2. Optimal location and number of FI

	Optimal place
1	3-11
2	2-9 & 3-11
3	2-9 & 3-11 & 5-6
Optimal number	3 FIs in 2-9 & 3-11& 5-6

Reliability indices (SAIFI, SAIDI, ENS) of this test feeder is shown in Figure 5 (a,b,c).). Figure 5-a shows, FI does not have any influence on SAIFI, because of FI only affect on repair or restoration time and fault location time consequently it affects on ENS and SAIDI as shown in Figures 5-b and 5-c.

5 Conclusion

With attention to problem of fault section estimation in PDS and FI application for solving it, a new objective function is presented in this paper. The proposed objective function is comprehensive because it is considered the four fundament necessary economical components (FI cost, unsatisfied consumer cost, ENS and operation and restoration cost). Solving this objective using MOGA, the optimum number and location of FIs are found. The results show this task can improve the reliability indices and increase benefits. The proposed method is tasted on two test cases, on of them is a real and practical feeder of Iranian PDN.

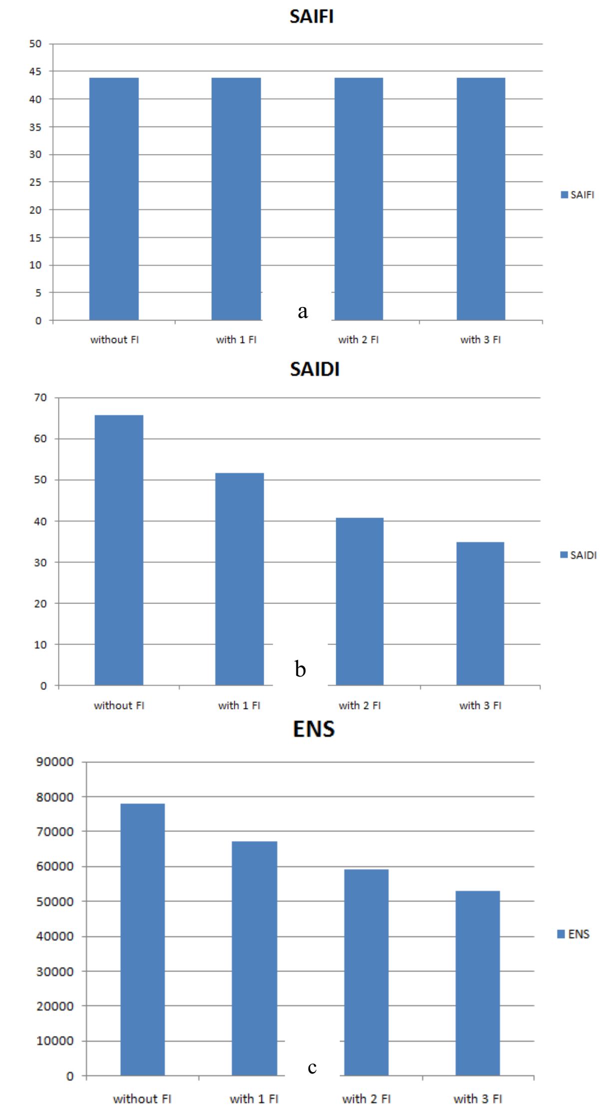


Figure 5. Reliability indices (SAIFI, SAIDI, ENS) of Bandargah feeder

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Appendix:
Bandargah feeder information

Table 3. Bandargah Feeder information

Sending Bus	Receiving Bus	Active power (kW)	Reactive power (kVAr)	Length(km)	Z
1	2	----	----	18	5.004+j6.408
2	3	----	-----	.5	0.139+j0.178
2	9	220	130	.7	04726+j0.6052
9	10	150	95	.3	0.17514+j0.22428
3	4	180	130	.7	0.1946+j0.2492
3	11	40	25	.6	0.5838+j0.7476
11	12	110	65	.5	0.1251+j0.1602
4	5	----	----	.65	0.1807+j0.2314
5	6	50	30	2.5	0.695+j0.890
5	13	50	30	.5	0.0695+j0.0890
6	7	150	80	.35	0.0973+j0.1246
7	8	110	75	.7	0.1946+j0.2492