

Optimal Recloser Placement by Binary Differential Evolutionary Algorithm to Improve Reliability of Distribution System

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ABSTRACT

In this context, a novel structure has been proposed for simple Differential Evolutionary (DE) algorithm to solve optimal recloser placement. For this, an operator is added to DE algorithm to adapt concept of the problem. Other contribution of this work is formulating a novel objective function. The proposed objective function has been formulated to improve four reliability indices which consists of four terms; i.e. System Average Interruption Duration Index (SAIFI), Cost of Energy Not Supplied (CENS), Average Interruption Frequency Index (MAIFI) and System Average Interruption Frequency Index (SAIFI). Simulation has been performed in 37 bus test system and the results of the proposed technique compared the related results of PSO algorithm.

Keywords

Optimal recloser placement, Binary differential evolutionary algorithm, Reliability improvement, Distribution system planning.

1. INTRODUCTION

A recloser is a device with the ability to detect phase and phase-to-earth overcurrent conditions, to interrupt the circuit if the overcurrent persists after a predetermined time, and then to automatically reclose to re-energize the line. If the fault that originated the operation still exists, then the recloser will stay open after a preset number of operations, thus isolating the faulted section from the rest of the system. In an overhead distribution system between 80 to 95 per cent of the faults are of a temporary nature and last, at the most, for a few cycles or seconds. Thus, the recloser, with its opening/closing characteristic, prevents a distribution circuit

being left out of service for temporary faults. Typically, reclosers are designed to have up to three open/close operations and, after these, a final open operation to lock out the sequence. One further closing operation by manual means is usually allowed. The counting mechanisms register operations of the phase or earth-fault units which can also be initiated by externally controlled devices when appropriate communication means are available [1].

By considering complexity of recloser placement problem, there are few references to study. In [2], improvements of System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) have been used as the objective function for optimal placement of DG and recloser by Ant Colony Optimization (ACO) method. The IEEE 69 and 394-bus test systems have been selected as test systems and the results of the proposed technique have been compared with results of GA in the same system. Authors in [3] has put the Momentary Average Interruption Event Frequency Index (MAIFI) term in the objective function of [2] which is in terms of three constrains; i.e. loading conditions, generation penetration level and power factor. Similar work has been performed in [4] by defining a novel composite reliability index.

Authors in [5] threshold value of the DG capacity has been calculated beyond recloser-fuse coordination is lost. The SAIFI, SAIDI, and Energy Not Supplied (ENS) have been selected as indices of reliability improvement of in the test system RBTS bus 2. In [6], a novel technique based on classify the recloser-fuse coordination status at fault conditions has been suggested to study the impact of distributed-generation penetration on recloser-fuse coordination. The main advantage of the proposed approach is that using the classification process for the coordination status discriminates between the cases that require an action

against DG penetration and the cases where no action is required.

In [7], a novel reliability index has been defined and the zone-network method used to evaluate this composite index in the presence of DG units. The simple GA has been improved by a mutli-population method and the influence of improper genetic parameters can be greatly decreased and premature convergence can be overcome effectively. Abdi et al. the recloser and autosectionalizer have allocated to improve reliability by a methodology based on cost/benefit analysis. A hybrid method based on IPSO algorithm and Monte Carlo simulation is employed. Simulation has been done in a practical test system in Iran [8].

Authors of Ref.[9] by finding optimal the number and location of recloser to improve reliability of feeders using genetic algorithm. The proposed method enjoys the simplicity of configuration, accuracy of the results and re-duction of the time consuming. The obtained results also show the applicability of the algorithm. The main features of a library of modules for representation of protective devices of distribution networks with DG have been presented and discussed present protection practices for distribution systems and DG interties, describe the implementation of protective devices in [10].

The optimal recloser placement has been performed in this paper using BDE algorithm. This paper consists of six sections. The proposed objective function has been formulated in Section 2. Section 3 discusses the proposed BDE algorithm. Solving optimal recloser allocation by the BDE algorithm has been presented in Section 5. The simulation results and comparison results of the proposed algorithm with PSO algorithm have been illustrated in Section 5. This work has been concluded in Section 6. Appendix

2. Formulation

The proposed objective function consists of four reliability indices have been considered in the objective function. These are two technical reasons for choosing these indices,

a) Indices of SAIFI, SAIDI and MAIFI are improvement indices from the viewpoint of costumers and CENS is from the viewpoint of distribution company.

b) Most faults in the distribution networks have transient nature and recloser is installed to respond to these faults. On the other hand, by increasing sensitivity of loads in recent years, the harmful effects of transient faults are more than permanent faults. Then MAIFI index has been applied to the objective function for enumeration of the number of transient faults in system. Indices of SAIFI, SAIDI and CENS are associated to permanent faults. Thus *RII* is formulated as,

$$OF = \sum_{k=1}^{ny} \left\{ \frac{SAIFI_k}{SAIFI_0} + \frac{SAIDI_k}{SAIDI_0} + \frac{MAIFI_k}{MAIFI_0} + \frac{CENS_k}{CENS_0} \right\} \quad (1)$$

where, *ny* is system lifetime. *SAIFI₀*, *SAIDI₀*, *MAIFI₀* and *CENS₀* are indices values before DG and recloser placement. By this technique values of four indices are normalized. The equations of the indices have been presented in Appendix A.

3. BINARY DIFFERENTIAL EVOLUTIONARY ALGORITHM

Evolutionary Algorithms (EAs) are of the most famous branches of intelligent computing which use some operators (crossover, mutation and other operators) to obtain the optimal solution from initial population. The DE algorithm is a member of EA family which was proposed originally in 1997 [11]. In general, the DE algorithm technique has five stages along with a sigmoid function which will be integrated in the algorithm to obtain the BDE algorithm. So, the BDE algorithm technique has six stages [12]-[13].

Stage i) Initialization: This algorithm is a population based algorithm, for this, initial population is produced as Eq. (7) to start optimization process. Dimensions of DE algorithm depends on the numbers of population, *P*, and variable, *V*.

$$\bar{Z}_{i,k}^G = \bar{Z}_L^{MIN} + rand \times (\bar{Z}_L^{MAX} - \bar{Z}_L^{MIN})$$

$$i \in [1, P], L \in [1, V] \quad (2)$$

where, *Z_L^{MIN}* and *Z_L^{MAX}* are lower and upper boundaries, respectively, which have been selected based on the problem requirements and *rand* produces a value between [0,1] randomly.

Stage ii) Mutation: The initialized population will mutate using Eq. (3). Mutation operator helps algorithm to escape from local minima. For this, three vectors are selected from initial population, randomly, called *Z₁*, *Z₂* and *Z₃* so that components of these vectors are not equal. Main criterion in production of mutated matrix is scaling factor, *F*. This parameter is selected in the range [0, 2]. The impact of second and third selected vectors, *Z₂* and *Z₃*, in mutation process are controlled by *F*,

$$\bar{Z}_{m,i}^{G+1} = \bar{Z}_1^G + F(\bar{Z}_2^G - \bar{Z}_3^G) \quad (3)$$

Stage iii. Crossover: By crossover operator, prior population (parent) is composed and the next population will be produced (children). Crossover operator won't be applied on all population, and applying criteria is the crossover rate, *CR*. This parameter is a real value in the range [0, 1]. If crossover rate is more than a random value, vectors from mutation step are selected; otherwise, selection is performed from initial population,

$$\bar{Z}_{c,ji}^G = \begin{cases} \bar{Z}_i^{G+1} & \text{if } \alpha_j \leq CR \text{ or } j = \gamma \\ \bar{Z}_i^G & \text{otherwise} \end{cases} \quad (4)$$

where, *α_j* and *γ* are chosen randomly from [1, ..., *V*].

Stage iv. Sigmoid Function: By applying sigmoid function to the obtained vectors from crossover operator, the population is transferred in binary space; i.e. zero and/or one. This work is carried out due to the performance nature of sectionalizing switches which are open and/or close.

$$X_{j,i}^G = \begin{cases} 1, & \text{if } rand < sigmoid(X_{j,i}^G) \\ 0, & \text{otherwise} \end{cases}$$

$$sigmoid(X_{j,i}^G) = \frac{1}{1 + e^{-X_{j,i}^G}} \quad (5)$$

Stage v. Selection: In this stage, the algorithm uses the selection operator to choose the optimal solution that has been achieved so far. In other words, selection operator decides between initial matrix, Z_i , and crossover matrix, Z_{ji} . If related solution of crossover vector, $f(Z_{c,i}^G)$, is less than or equal to the solution corresponding with initial population, $f(Z_i^G)$, the crossover vector will be selected. This concept has been shown in Eq. (6),

$$\bar{Z}_i^{G+1} = \begin{cases} \bar{Z}_{c,i}^G & \text{if } f(\bar{Z}_{c,i}^G) \leq f(\bar{Z}_i^G) \\ \bar{Z}_i^G & \text{otherwise} \end{cases} \quad i = 1, \dots, P \quad (6)$$

Stage vi. Termination Criteria: To terminate the algorithm, there are two ways; reaching to the optimal solution or reaching the maximum iteration. In optimization problem, the second criterion has been used.

4. SOLVING THE OSS PROBLEM BY THE BDEA TECHNIQUE

The concept and equations of objective function and BDE algorithm approach have been presented in sections 3-4, respectively. In this section, solving the optimal recloser problem by BDE algorithm has been introduced. Figure 1 shows flowchart of solving the recloser placement by the BDE algorithm.

5. SIMULATION RESULTS

The IEEE 37-bus radial distribution network has been selected as test system. Figure 2 shows single line diagram of 37-bus distribution system. Three scenarios have been introduced based on the number of the installed recloser(s); which are: one and two as well as three reclosers. In each scenario, six parameters of the proposed algorithm have been compared with related values of PSO algorithm, which are: CENS, SAIDI, SAIFI, MAIFI, the value of objective function and location of the installed recloser.

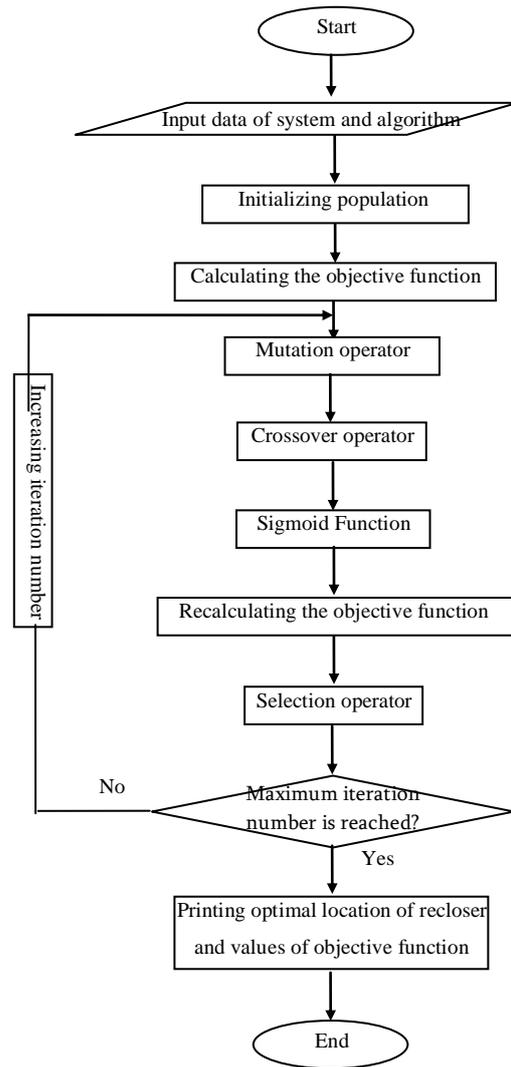


Figure 1. Solving the optimal recloser placement problem using BDE algorithm

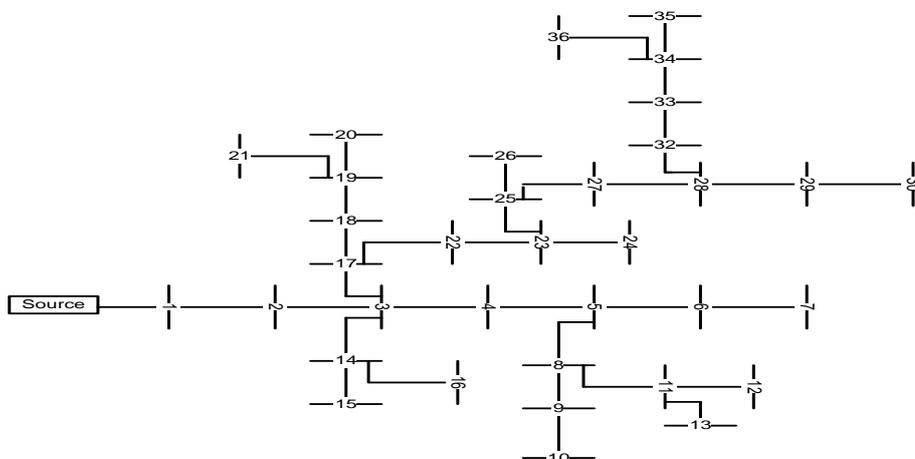


Figure 2. Single line diagram of the test system

5.1 Placement of 1 recloser

In first scenario, the optimal location of one recloser is determined. Table 1 shows the optimal values of reliability indices and objective function as well as optimal location of this recloser.

Table 1. Results of 1 recloser placement

Tech.	CENS	SAIDI	SAIFI	MAIFI	OF	Locatio
Without	148831313	145.843	140.043	32.093	4.000	-
PSO	45541168	35.169	37.836	8.671	1.087	22
BDE	36439346	29.109	30.303	6.927	0.876	22

By considering results of Table 1, in all cases the BDE algorithm presents better solution respect to PSO algorithm. The values of CENS, SAIDI, SAIFI and MAIFI of BDE algorithm are %19.98, %17.23, %19.91 and %20.11 less than related values of PSO algorithm, respectively. The objective function of BDE algorithm is %19.41 less than objective function of PSO algorithm. The location of recloser of two methods is similar.

5.2 Placement of 2 reclosers

Optimal values from siting of two reclosers in the test system have been listed in Table 2.

Table 2. Results of 2 reclosers placement

Tech.	CENS	SAIDI	SAIFI	MAIFI	OF	Location
Without	148831313	145.843	140.043	32.093	4.000	-
PSO	226638912	28.301	36.679	8.405	0.870	2, 22
BDE	15412361	19.836	25.635	5.974	0.608	2, 22

Due to Table 2, buses of 2 and 22 are optimal locations for installing recloser. The CENS, SAIDI, SAIFI and MAIFI of the proposed algorithm is %31.99, %29.91, %30.11 and %28.92 less than of CENS, SAIDI, SAIFI and MAIFI of PSO algorithm, respectively. The objective function of PSO algorithm is %43.09 more than corresponding value of BDE algorithm.

5.3 Placement of 3 reclosers

Finally three recloser have been considering to install in test system. The optimal results of BDE and PSO algorithm for this scenario have been listed in Table 3.

Table 3. Results of 3 reclosers placement

Tech.	CENS	SAIDI	SAIFI	MAIFI	OF	Location
Without	148831313	145.843	140.043	32.093	4.000	-
PSO	22380105	27.994	36.348	8.329	0.861	2, 22, 25
BDE	15128572	20.713	25.404	5.7428	0.604	2, 22, 25

According to results of Table 3, the four reliability indices of the BDE algorithm are %32.4017, %26.01, %30.11

and %31.05 less than CENS, SAIDI, SAIFI and MAIFI of PSO algorithm, respectively. In addition to these indices, the objective function of the proposed algorithm is %29.849 less than related value of PSO algorithm. The optimal locations for installation these reclosers by two methods are: buses 2, 22 and 25.

6. CONCLUSION

In this paper a novel algorithm has been presented based on DE algorithm to find optimal location of recloser in distribution system. The objective function has been formulated based on improvement of transient and permanent faults from view of costumer and Distribution Company. Simulation has been performed in 37 bus test system and results of the proposed BSE algorithm have been compared with related values of PSO algorithm. From simulation results, the proposed algorithm presents better solution respect to the PSO algorithm in three scenarios and among five parameters (which are: CENS, SAIDI, SAIFI, MAIFI and objective function). Location of recloser of two algorithms is similar in three scenarios.

Appendix A. Calculation of reliability indices

To calculate reliability indices, SAIDI and CENS, analytical method based on error modes and their effects (FMEA) is used [14]. Accordingly the mentioned parameters are calculated using Eqs. (A.1) to (A.8).

$$SAIDI_i = \left(\lambda_{sys} \frac{L_i}{L_t} \right) \left[\left(r_{loc} \frac{L_{loc,i}}{L_t} \right) \left(\frac{N_{loc,i}}{N_t} \right) + r_{rep} \frac{N_{rep,i}}{N_t} \right] \quad (A.1)$$

$$EENS_i = \left(\lambda_{sys} \frac{L_i}{L_t} \right) \left[\left(r_{loc} \frac{L_{loc,i}}{L_t} \right) (P_{loc,i}) + r_{rep} P_{rep,i} \right] \quad (A.2)$$

$$SAIFI_i = \left(\lambda_{sys} \frac{L_i}{L_t} \right) \left[\left(\frac{L_{loc,i}}{L_t} \right) \left(\frac{N_{loc,i}}{N_t} \right) + \frac{N_{rep,i}}{N_t} \right] \quad (A.3)$$

$$MAIFI_i = \left(\lambda_{ins} \frac{L_i}{L_t} \right) \left[\left(\frac{L_{loc,i}}{L_t} \right) \left(\frac{N_{loc,i}}{N_t} \right) + \frac{N_{rep,i}}{N_t} \right] \quad (A.4)$$

$$SAIDI_{sys} = \sum_{i=1}^k SAIDI_i \quad (A.5)$$

$$CENS_{sys} = \sum_{i=1}^K CENS_i \quad (A.6)$$

$$SAIFI_{sys} = \sum_{i=1}^k SAIFI_i \quad (A.7)$$

$$MAIFI_{sys} = \sum_{i=1}^k MAIFI_i \quad (A.8)$$

where:

$EENS_i$: Energy Not Supplied due to an error in the i th region
 $SAIDI_i$: System Average Interruption Duration Index due to an error in the i th region

λ_{sys} : Annual failure rate of system
 λ_{ins} : Instant failure rate of system
 l_i : Length of the i th region
 l_f : Total length of feeder
 r_{loc} : Average time for locating the fault
 $l_{loc,i}$: The length of region which is de-energized for locating the fault due to an error in the i th region
 $N_{loc,i}$: Total number of customers who are de-energized for locating the fault due to an error in the i th region
 N_i : Total number of system customers
 r_{rep} : Average time to repair a fault
 $N_{rep,i}$: The number of customers who are de-energized for repairing the fault due to an error in the i th region
 C_{ns} : The average cost of a 1 kWh outage
 $P_{loc,i}$: The average outage active power for repairing the fault due to an error in the i th region
 $P_{rep,i}$: The average outage reactive power for repairing the fault due to an error in the i th region

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