International Journal of Research and Technology in Electrical Industry

journal homepage: ijrtei.sbu.ac.ir

Shahid Beheshti University

Sectionalizing Switches Placement in Distribution Networks Using BTLBO

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ARTICLEINFO

Article history:
Received 01 April 2023
Received in revised form 11 June 2023
Accepted 17 September 2023

Keywords:
Switch
Binary teaching learning-based optimization
Placement
Mixed integer linear programming

ABSTRACT

Sectionalizing switches (SS) and lines play an essential role in improving the performance of the distribution automation system as well as reducing the outage duration of power grid customers. The operation of the sectionalizing switches and whether the lines are energized or de-energized are also dependent on each other. Considering the structural complexities related to the mathematical modelling of such problems, optimizing the planning and performance of switches and lines usually requires the use of heuristic and meta-heuristic approaches or oversimplification of network complex topology. To deal with such issues, this research presents an efficient computational model for reliability-based simultaneous switching in distribution networks with complex topologies using binary teaching learning-based optimization (BTLBO) algorithm. The performance of proposed model is demonstrated on the IEEE 123-bus system. The results show that the proposed model is effective for placement of sectionalizing switches to enhance power system reliability.

1. Introduction

Electrical energy has become so important in today's world that it plays a vital role in our daily life that even short-term blackouts, and service interruptions cannot be tolerated. As a result, regulations have been imposed in many countries to ensure uninterrupted and low-interruption services to end users, which has increased reliability indicators. In particular, because the majority of service interruptions are due to failures at the distribution network level, increasing the reliability of distribution networks (DNs) over upstream networks has received more attention in recent years [1].

In this sense, the installation of sectionalizing switches (SS) in distribution networks has always been considered as an essential, and effective tool to reduce the duration of interruption of network customers, and as a result, increase the reliability of distribution services.

The first mathematical model to ensure the achievement of the best method for solving the reliability-based switch placement problem is presented by Abiri et al. in [2]. In this research, a mixed integer linear programming (MILP) formula is developed to optimize the costs of remote-controlled switch (RCS) placement. This proposed MILP model was able to achieve the general optimal point, but it was used for use in systems with simple topology. As a result, researchers have conducted many studies in this field in recent years. In this regard, Sirto et al. considered the effect of ground fault in [3] then, the effects of distributed generation (DG) by Heydari et al. in the MILP model [4].

Also, the authors developed MILP formulas to determine the simultaneous placement of fault markers,

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http://dx.doi.org/10.48308/ijrtei.2023.103336

manual switch (MS) and RCS. While the MILP-based methods were useful for finding the global optimal solution in limited and specific times, they considered assumptions in their research to simplify the models, which, as a result, cannot be used for real distribution networks with complex topologies [5].

Izadi and safdarian, in [6] proposed a method to solve the switch placement problem by presenting the MILP model based on the random nature of possible failure cases, and the unexpected duration of the RCS repair time. The random nature of contingencies affects the value of RCS, and imposes significant financial risk on RCS deployment projects. The results showed that the risk priority of distribution companies significantly affects the number and location of switches, and also the use of one type of switch leads to an increase in costs.

Ray et al. performed the optimal placement of switches in radial distribution networks to improve reliability indices using differential search (DS) algorithm. In this article, DS algorithm is used to find the optimal number and location of RCS in radial distribution networks. Also, only one type of switch (RCS) has been used for optimization, which can be one of the weaknesses of this model in solving this problem [7].

Farajollahi et al. considered the effect of SS failure for their optimal placement in the distribution network. In this study, they investigated the importance of switch failure in the issue of switch placement, and the amount of change in the allocation of switches in a network. The obtained results clearly showed that the switch failure limits the number of switches allocated in the system, and worsens the reliability indices [8].

In the next study, the optimization of switch and transmission lines in reliability-based distribution network is discussed. In this article, a model based on mathematical programming is presented for the simultaneous placement of both manual and control type sectionalizing switches in distribution networks with the aim of increasing reliability indicators by considering the advantages and disadvantages in practical applications. The significant increase in costs made it inefficient in complex networks with lateral feeders [9].

Li et al. in addition to the simultaneous placement of the sectionalizer and the fault indicator, their model has been done in networks with multiple branch lines. The objective function is to minimize the total costs (which includes the cost of equipment plus the cost of interruption) under technical and economic constraints. The proposed method in this study solves the optimization problem in distribution networks by presenting a MILP model, and also considers the differences between different types of equipment [10].

With the aim of dealing with the shortcomings of past works, in this article, a new model based on MILP is presented for placing SSs in the distribution network with complex topologies. Since the concepts used in previous MILP models cannot be used to solve such a complex optimization, the proposed formulation in this paper generalizes the reliability evaluation model without making any simplifications. So that it can be used to determine the type and location of SSs installed on the lines. Binary Teaching Learning Based Optimization (BTLBO) has also been used to solve the problem [11] ,and the results obtained confirm the effectiveness of the method and algorithm.

Table I shows the main differences of this research with other references.

Table I. Comparative of innovations.

Feature	[2]	[3]	[4]	[5]	[6]	[8]	[9]	This model
I	✗	✗	✗	✓	✗	✓	✓	✓
II	✗	✓	✗	✓	✓	✓	✓	✓
III	✗	✗	✗	✗	✗	✗	✗	✓
IV	✓	✗	✓	✓	✓	✓	✓	✓
V	✗	✗	✗	✓	✗	✗	✓	✓
VI	✗	✗	✗	✗	✗	✗	✗	✓

I: Both types of sectionalizer for installation
II: Practical efficiency of the model
III: Modeling sub-feeders
IV: Convergence and optimal solution
V: Reliability assessment
VI: Tie switch placement

2. Problem Assessment

However, the introduced MILP models did not propose a solution regarding the optimal placement of sectionalizing switches in a distribution network with complex topologies that include a high number of side feeders. While some optimization models, unlike the MILP models introduced in the previous section, used heuristic algorithms to optimize the reliability-oriented switch placement problem, and did not make any of the simplifying assumptions of other researchers.

More precisely, the solution presented in this research improves the reliability indicators so that it can be used to determine the type and location of SSs, which is also general for distribution networks with complex topology. The presented model none of the simplifying assumptions for locating SSs and determining their type are taken into account. Also, because the proposed solution is expressed by the MILP model, it is guaranteed by general solvers to easily solve it in limited time, and also to reach the optimal solution.

3. Solving Algorithm

The flowchart drawn in Fig. 1 shows the problem-solving process. According to Fig. 1, in the proposed method, first, the information of all network buses, which includes active and reactive powers, is given as input to MATLAB software; Then, by spreading the load, information including the voltage and current of each bus is extracted.

Now, by using teaching learning based optimization (TLBO), locations for switches are selected, then according to the obtained values of the objective function of the problem, new candidate locations are selected to improve the objective function. The limitations of this optimization are the amount of budget allocated by the distribution company, and the number of switches used in the network. If the number of switches placed in the network is not within the range considered by the proposed algorithm, the placement is repeated by the algorithm until in this range.

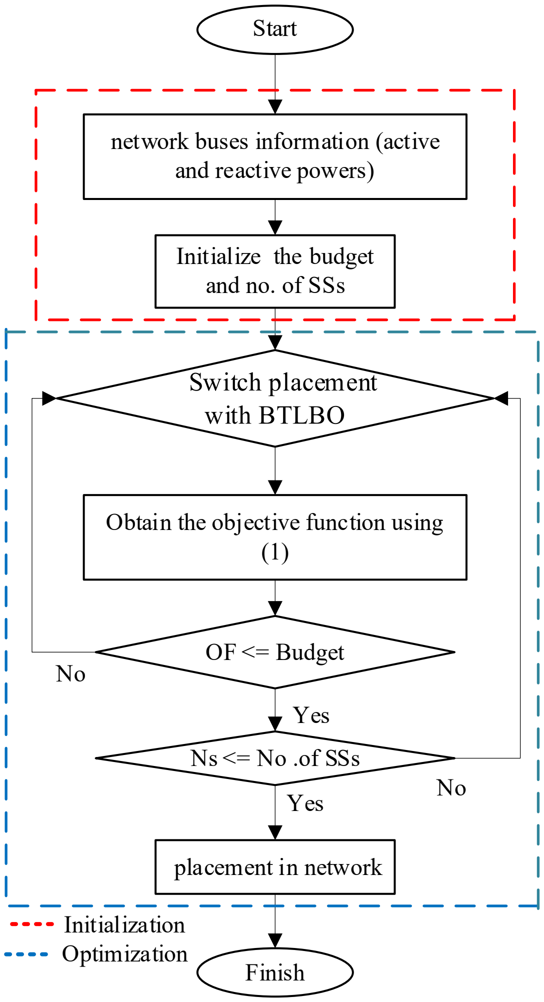

Fig. 1. Problem-solving process.

The output of this program includes the location of the SSs as well as their type, which is manual and remote. Also, the switches that connect two feeders are introduced as normally open switches, which can change the operation of the distribution network from radial mode to circular mode. This switch has two types, manual and remote, depending on the conditions of the area where it is placed.

4. Problem Formulation

The goal is to find a trade-off between uncertainty costs, and the allocation of SSs; Equation (1) presents the objective function of the problem:

$$minOF = \frac{\alpha}{1-(1+\alpha)^{-U}} Inv + Op + \delta^{T} vEENS + PC \tag{1}$$

where Inv the annual system cost includes the annual value of the switch investment cost, and U the useful life of the switches and lines, and α the annual interest rate, and Op the operating cost, and v the annual expected revenue reduction per unit of expected energy not supplied (EENS), and PC is penalty cap, and δ^T determines the annual coefficient [9], which is obtained from (2):

$$\delta^{T} = \alpha\left(\frac{(1+g)^{T}-(1+\alpha)^{T}}{(g-\alpha)(1+\alpha)^{T}} + \frac{(1+g)^{T-1}}{\alpha(1+\alpha)^{T}}\right) \tag{2}$$

This coefficient is one of the relations of engineering economy, which has an effect on the changes in the inflation rate, and the changes in the load that occur in the region during a period of time. where g is the annual load growth rate, and T is the demand growth period.

For example, this coefficient for an 8-year period with $g = 0.02$, and $\alpha = 0.09$ is equal to 1.15. Considering this coefficient, EENS value is affected for a period of time, and increases the objective function.

Equation (3) determines the total investment cost for SSs. This investment is related to the purchase costs of manual and remote switches for tie lines and connection lines between feeders.

$$Inv = \sum_{l \epsilon L}\sum_{e \epsilon E}\left(x_{l,e}^{R} IC^{R} + x_{l,e}^{M} IC^{M}\right) + \sum_{r \epsilon \Psi}\left(x_{r}^{R} IC^{R} + x_{r}^{M} IC^{M}\right) \tag{3}$$

where $x_{l,e}^{M,R}$ is a binary variable related to the presence or absence of a manual or remote switch for feeder section l,e, and $x_{r}^{M,R}$ is a binary variable related to the presence or absence of tie switch (with a value of zero or one).ψ is a set of selected locations.

Equations (4) determine the operating cost for the SSs.

$$Op = \sum_{l \epsilon L}\sum_{e \epsilon E}\left(x_{l,e}^{R} OC^{R} + x_{l,e}^{M} OC^{M}\right) + \sum_{r \epsilon \Psi}\left(x_{r}^{R} OC^{R} + x_{r}^{M} OC^{M}\right) \tag{4}$$

where IC^R and IC^M are the investment costs for remote and manual switches, r is the index for optimal tie switch locations, OC^R and OC^M are the operating and maintenance costs of remote and manual switches.

4.1. Reliability Assessment

The installation of sectionalizing switches on new lines determines the EENS, and the system average interruption duration (SAIDI) to obtain a practical assessment of the reliability value for distribution companies. Based on this, equation (5), and (6) calculates $EENS$ and $SAIDI$.

$$EENS = \sum_{l \epsilon L}\sum_{n \epsilon \Omega} \tau_{l,n} P_{n} \tag{5}$$

$$SAIDI = \frac{\sum_{l\epsilon L}\sum_{n\epsilon\Omega}\tau_{l,n}N_n}{\sum_{n\epsilon\Omega}N_n} \qquad (6)$$

where Pn is the electricity demand at node n, and Nn is the number of consumers connected to node n, and Ω is a set of all load nodes, and $\tau_{l,n}$ is the annual interruption period for customers connected to node n due to failure in feeder section l, which is specified in (7).

$$\tau_{l,n} = RT_l\lambda_l; \{\forall l\epsilon L, \forall n\epsilon\Omega\} \qquad (7)$$

where RT_l is the repair time for feeder section l, and λ_l is the failure rate of feeder section l.

If exists the sectionalizing switch (MS or RCS), the annual interruption period will be in (8) and (9).

$$\tau_{l,n} \geq ST^M\lambda_l; \{\forall l\epsilon L, \forall n\epsilon\Omega\} \qquad (8)$$

$$\tau_{l,n} \geq ST^R\lambda_l; \{\forall l\epsilon L, \forall n\epsilon\Omega\} \qquad (9)$$

Where ST is the switching time of the sectionalizing switches (MS or RCS). With the presence of sectionalizing switches in the network the annual interruption period is equal to the duration of the operation of the switch. It is possible that the operation of switches may also suffer from errors or failures, which makes the duration of the annual interruption period longer than the operation time of the switches.

In this study, according to the SAIDI, distribution companies incur costs. If this indicator exceeds the standard, the distribution company must pay a penalty. Fig. 2 shows the method of calculating this penalty.

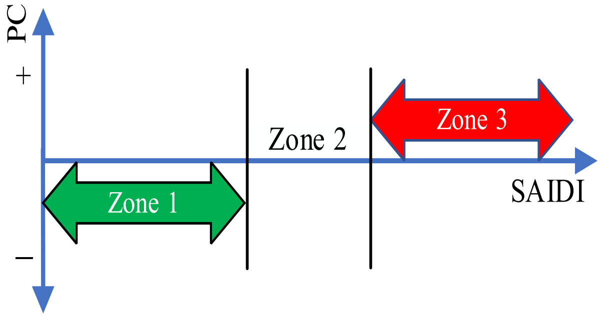

Fig. 2. Penalty graph.

In Fig. 2, three zone are defined for the horizontal graph. Zone 1 is a region of SAIDI where the penalty is negative, which improves the objective function. In zone 2, the range of SAIDI is in the form where the penalty is zero (it is in the standard range), and in zone 3, which exceeds the permissible limit in SAIDI and incurs a penalty, which increases the objective function [5].

5. Optimization using BTLBO

To solving the problem of determining the type and location of SSs, the binary teaching learning based optimization algorithm has been used. Which is one of the meta-heuristic algorithms that are effective and strong in solving MILP optimization problems [12, 13].

In this part, a string of binary numbers (which are 0 and 1) are produced in BTLBO (including n bits), the first part of which means the installation or non-installation of the switch, and the second part of the generated binary numbers. 0 and 1 indicate that the switch is manual or remote (according to Table II, $n/2$ is the number of network buses).

This process of generating binary numbers continues until the best candidate location for the switches is produced.The selected values for the variables are specified in Table III [14].

Table II. Binary structure for each gene.

Bit	Bit type	Value	Description
1,…, $n/2$	binary	0	No
1,…, $n/2$	binary	1	Yes
$n/2$ +1,…, n	binary	0	M Switch
$n/2$ +1,…, n	binary	1	RC Switch

Table III. Values of variables.

Variable	Value	Variable	Value
α(%)	8	IC^M($)	500
U(year)	15	IC^R($)	4700
T(year)	10	OC^R($)	0.02*IC^R
g(%)	3	OC^M($)	002*IC^M
ST^R(hour)	0~0.1	$\lambda_l(\frac{Failure}{year})$	2
ST^M(hour)	0~1	V($/MWh)	120

6. Case Study Network

Fig. 3 shows the single-line diagram of IEEE 123-bus test system. In this network, the active power is 7060 (kW), and the reactive power is 3880 (kVar) [15]. Also, the allowed voltage range is between 0.93 and 1.05 p.u. Also, the red icons indicate the occurrence of a fault on that feeder or section.

As shown in Fig. 3 when a fault occurs in the specified places on the system a part of the network is shut down, and this shutdown continues until the defective part is repaired. For example, if a fault occurs on the line between buses 57 and 60, a large part of the network will be shut down. But by placing a switch on this line, we can disconnect the defective part from the network, and by connecting the communication switch between buses 39 and 66, the remaining part of the network can be electrified, and the amount of damage caused by it can be reduced to a great extent.

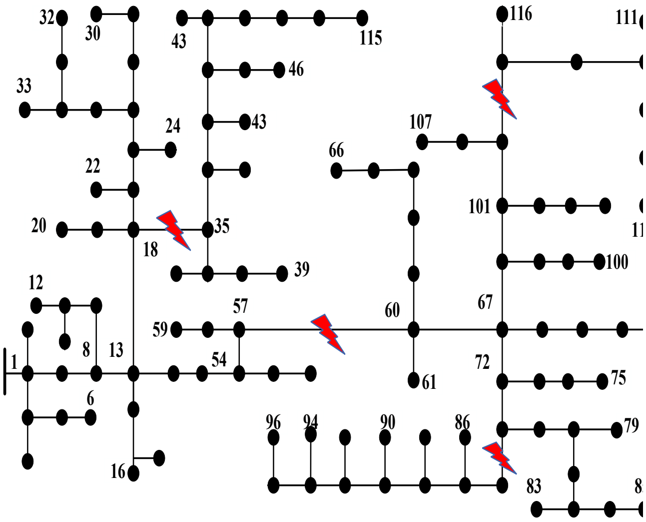

Fig. 3. IEEE 123-bus system.

Fig. 4 shows the single-line diagram of the studied system, the IEEE test network of 123-bus after optimization. In this research, load sensitivity is not considered, and all subscriber's and consumers are equally important.

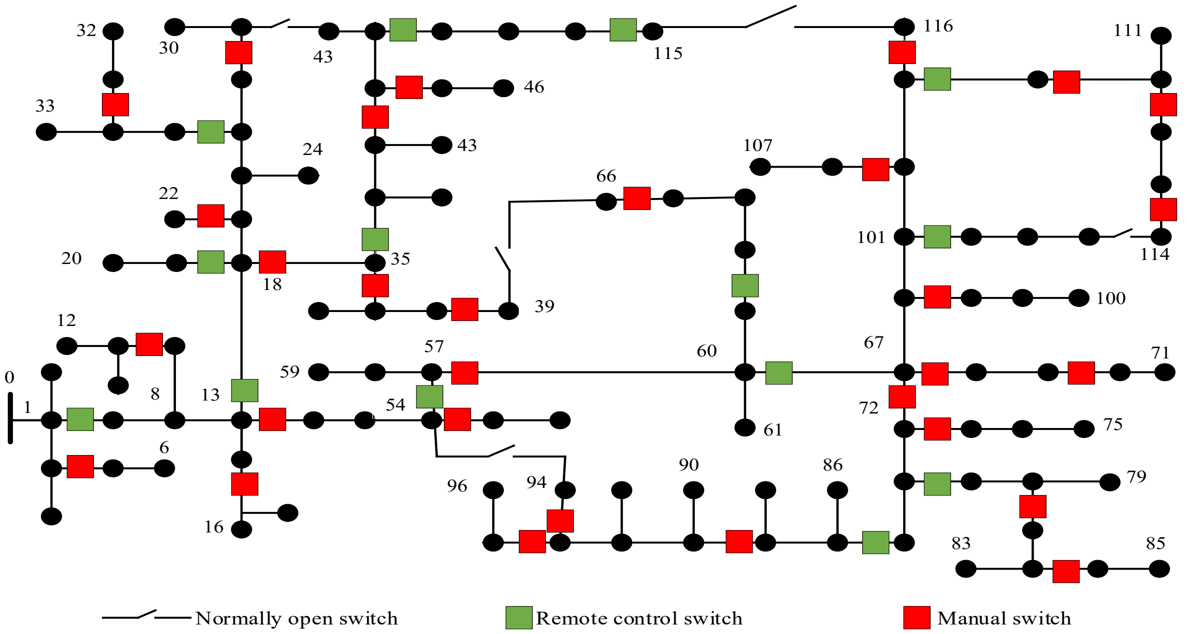

Fig. 4. IEEE 123-bus system after optimization.

7. Simulation Results

To assess the effect of SS placement optimization, three following cases are studied for the experimental distribution network:

Case 1) Placing the SSs in the distribution network using the BTLBO algorithm.

Case 2) placing the SSs in the distribution network using Binary Particle Swarm Optimization (BPSO).

Case 3) Placement of SSs in the distribution network without optimization.

- In case 1, the placement of switches is done using the TLBO algorithm. In this optimization, the number of students is 60, the number of generations is 100, and the number of variables, which are the system busses, is considered to be 123.
- In case 2, the placement of switches is done using the BPSO optimization algorithm. The process of running the program is done as mentioned. This algorithm is based on the population in such a way that answers are generated first, and the best answer is selected according to the fitness function. For 100 repetitions of this algorithm [13], the optimal solution has been achieved, and their results are analyzed.
- In case 3, placement has been done without using optimization algorithms. In this way, the switches are experimentally placed in the places where the fault occurred before.

The convergence process of the objective function of the problem for case 1 and case 2 are shown in Fig. 5 and Fig. 6 which, was obtained after 60 and 100 iterations.

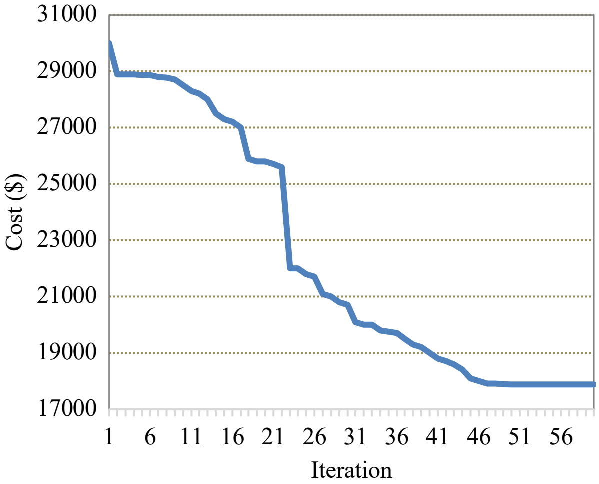

Fig. 5. Convergence process (case 1)**.**

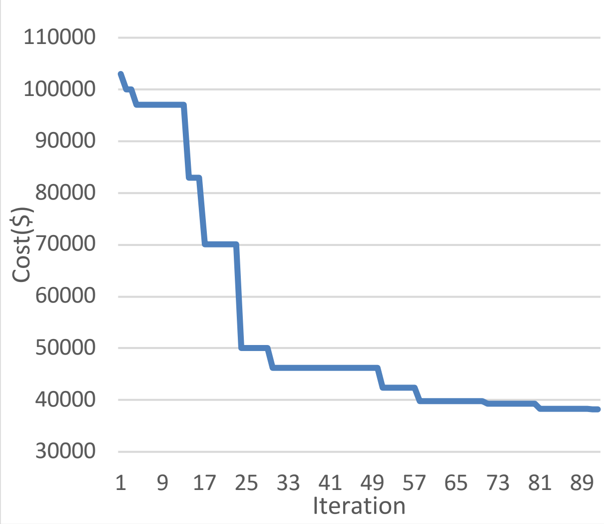

Fig. 6. Convergence process (case 2)**.**

As it is clear from Fig. 5 and Fig. 6 the speed of convergence in case 1 is improved compared to case 2, but this issue cannot create an advantage, because in modeling this problem, the speed of solving is not very important. However, the value of the objective function is finally optimized in case 1 compared to case 2, and this can be a reason for using BTLBO algorithm to solve this problem.

Numerical results for all three investigated cases are given in Table IV. In this table, the values of EENS, and SAIDI as well as the number of switches used (both MS and RCS) are given. In this table, depending on the type of switch placed in the buses, and their unsupplied load the cost of each bus in each part Is different. The cost function of each bus for case 1 is shown in Fig. 7, and for case 2 in Fig. 8, and for case 3 in Fig. 9.

Table IV. Numerical results.

Case study	OF(k$)	EENS(MWh/year)	SAIDI(hours/cust)	No. of RCSs	No. of MSs
Case 1	17.880	23.901	0.931	14	30
Case 2	38.209	33.012	2.150	20	12
Case 3	76.761	79.317	2.801	18	5

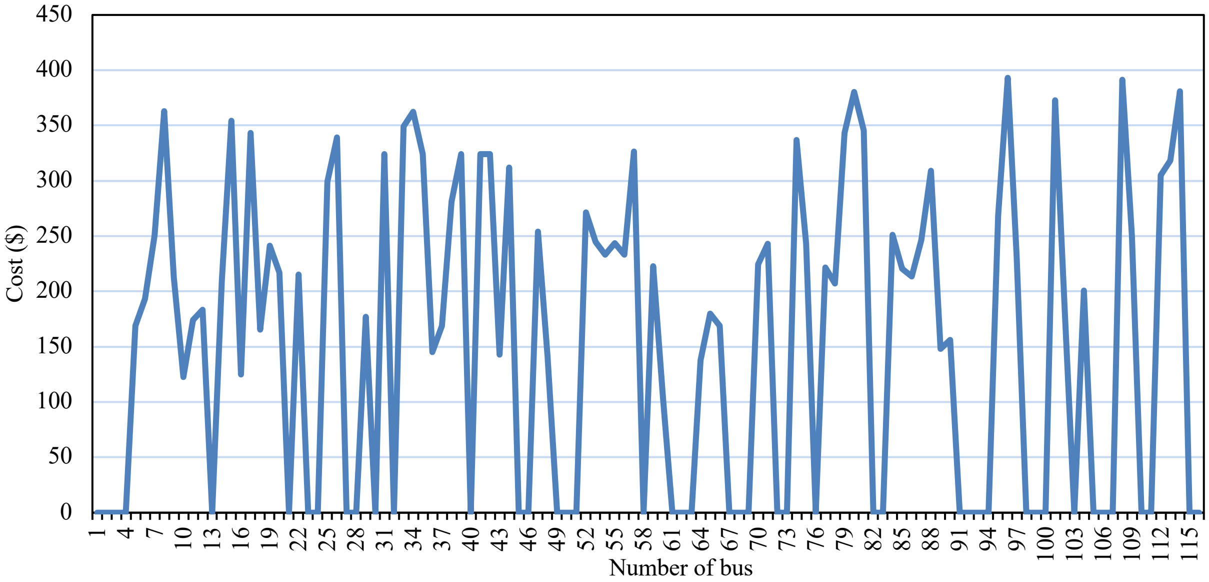

Fig. 7. Cost of each bus for case 1**.**

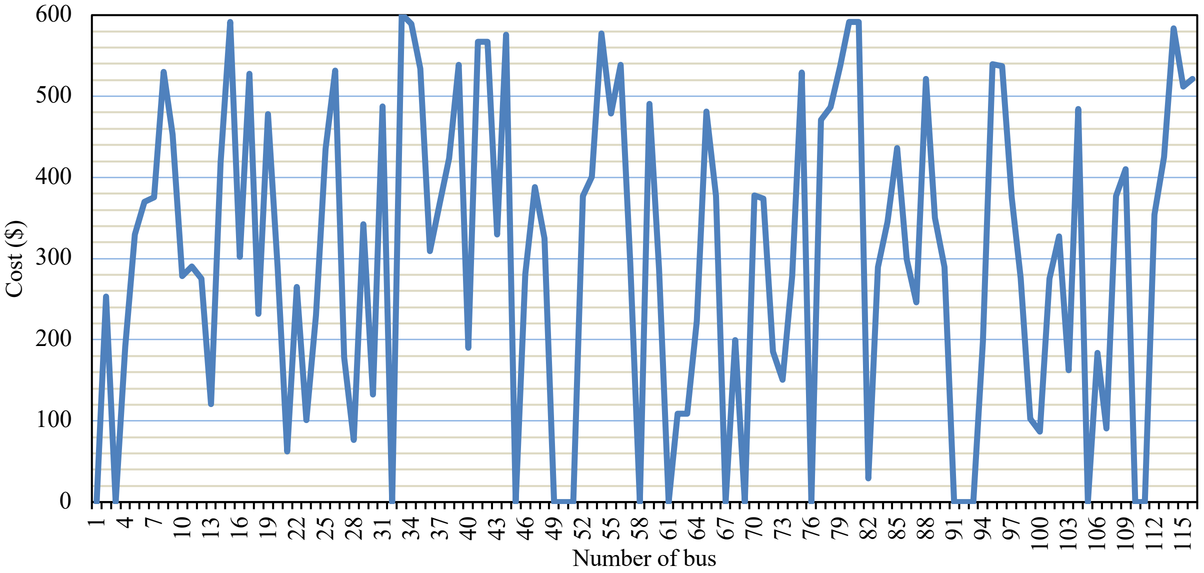

Fig. 8. Cost of each bus for case 2.

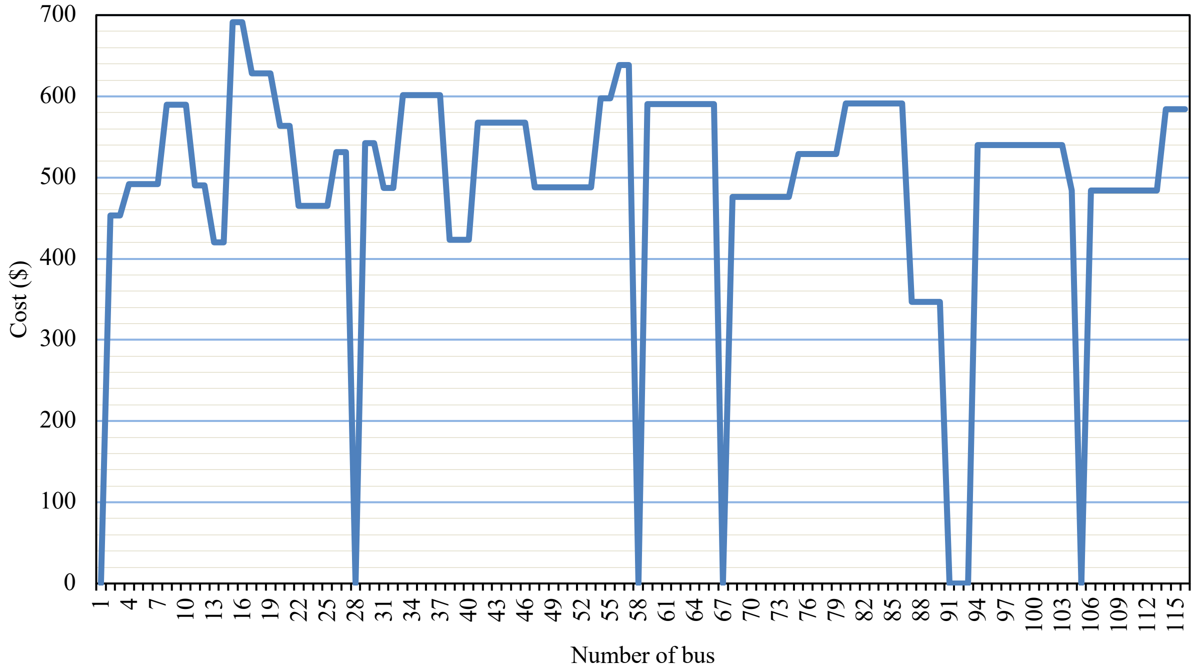

Fig. 9. Cost of each bus for case 3**.**

The optimal location of the switches was seen in Fig. 4. in which the type of switches placed on the buses is known. Also, in normal mode, normally open switches are open, and if necessary, these switches are closed and communicate between feeders. According to the results of Table IV, the use of Algorithm BTLBO will reduce overall costs. Reliability indices in case 1 have improved compared to case 2. But the number of switches in case 1 is more than case 2 which improves reliability indicators and ultimately reduces overall costs.

In addition, in Fig. 7 and Fig. 8 and Fig 9 depending on the type of switch placed in the buses, and their unsupplied load and the duration of the line repair at the time of the fault, the amount of costs incurred by each bus is known. In some of these buses, the total cost is 0, which is the reason for the lack of blackouts and incurring costs.

For example, in the case of one number of switches, it is more than the other two cases, which causes less shutdowns due to faults and lower overall costs. Also, in case 2 compared to case 3, the number of switches is more, which has improved the objective function compared to case 3.

In the case of 3, placement has been done using experience, and knowing which location is more cost-effective. which has reduced the number of switches compared to the other two cases. The increase in shutdowns and the level of dissatisfaction when a fault occurs in case 3 has caused increases in the function of the values of EENS and SAIDI, and finally the value of the objective function has also increased.

For a better understanding of the results in Fig. 10, and Fig. 11, a comparison between the values of EENS and SAIDI for three cases has been made.

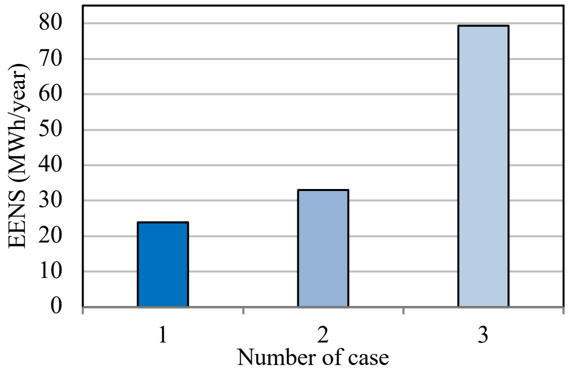

Fig. 10. Reliability index (EENS)**.**

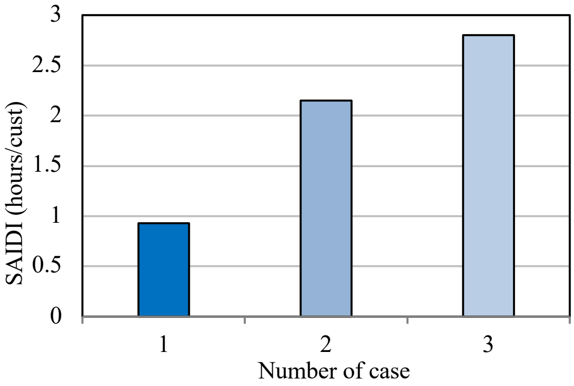

Fig. 11. Reliability index (SAIDI).

The sensitivity of the objective function to the number of switches installed on the lines (both MS and RCS) is shown in Fig. 12. Different situations of placing the number of switches on the lines have been investigated, which shows that after the number of 14 RCS and 30 MS, increases the value of the objective function.

Or, for example, in mode 6, 60 switches (32 manual and 18 control) have been used in the network, and the objective function has changed from $ 17,880 to $ 37,651, which is not economical compared to mode 5.

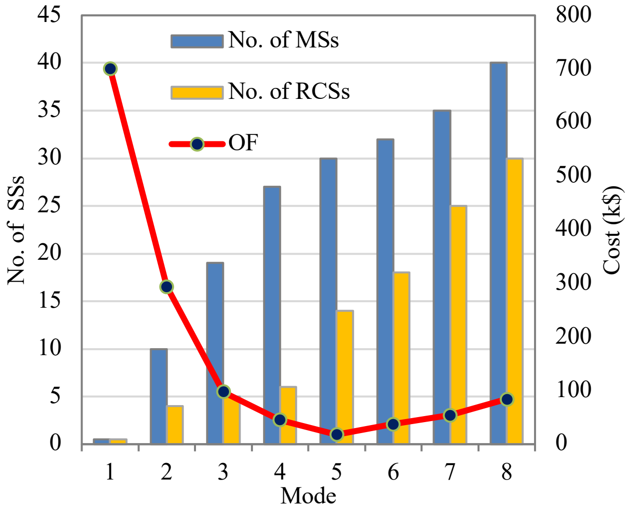

Fig. 12. Sensitivity analysis.

8. Conclusion

This study presented a method based on BTLBO. This model has been implemented on the IEEE 123-bus system, and the reliability indicators are analyzed. The results clearly show that with the presence of sectionalizing switches, and determining their type in the distribution network, we will increase the reliability of the network, and reduce the overall costs. Although investment and installation costs increase as the number of cross-sectional switches in the network increases, as reliability increases, reliability costs decrease and overall costs decrease.

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