Indonesian Journal of Electrical Engineering and Computer Science
Vol. 2, No. 1, April 2016, pp. 1 ~ 10
DOI: 10.11591/ijeecs.v2.i1.pp1-10

A Novel Method Based on Teaching-Learning-Based Optimization for Recloser Placement with Load Model Consideration in Distribution System

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Abstract

This paper proposed a novel technique based on teaching-learning-based optimization (TLBO) algorithm in order to find optimal placement of reclosers in the distribution networks which is applied to improve reliability. Reclosers use to eliminate transient faults, faults isolation, network management and enhance reliability to reduce customer outages. According to recloser role in network reliability, the cost for the installation and maintenance must be sustained by distribution companies. Therefore, selecting sufficient number and suitable location for reclosers are important issue. In this paper, the proposed objective function for optimal recloser number and placement has been formulated to improve three reliability indices which consists of three terms; i.e. System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI) and Average Energy Not Supplied (AENS). Besides the load model effectiveness has been considered to the simulation. To verify the efficiency of proposed method, it has been conducted to IEEE 69-bus radial distribution system. The obtained simulation results demonstrate the reliability improvement.

Keywords*: optimal recloser placement, reliability improvement, Load model, TLBO*

1. Introduction

In distribution power systems reclosers use to eliminate transient faults, faults isolation, network management and enhance reliability indices. 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-energized 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 percent of the faults are of the temporary nature and last, at the most, for a few cycles or seconds. Thus, the recloser, with its opening/closing characteristics, 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 sequences. 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].

Because the high cost of recloser the usage must be economically justified for distribution companies. The number and recloser location include many factors e.g. customer type, load variation, installation and maintenance cost and etc. Many researches have been done for placement of protective devices.

Optimum switch placement has carried out with QEA-based algorithm to improve customer service reliability [2]. A new composite objective function of investment cost and reliability on optimum placement of line switch is presented [3]. Simulated annealing optimizing algorithm has discussed [4]. Placement formulated by nonlinear binary programming [5]. Sectionalizer and recloser placement has been done to increase reliability by using discrete event simulation [6]. Improvements of System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) have been used as the objective function

Received January 21, 2016; Revised March 3, 2016; Accepted March 14, 2016

for the 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 the results of GA in the same system [7]. Momentary Average Interruption Event Frequency Index (MAIFI) has put in the objective function of [7] which is in terms of three conditions; i.e. loading conditions, generation penetration level and power factor [8]. Similar work has been performed by defining a novel composite reliability index [9]. Threshold value of the DG capacity has been calculated beyond recloser-fuse coordination is lost. The SAIFI, SAIDI, Energy Not Supplied (ENS) have been selected as indices of reliability improvement in the test system RBTS bus 2, [10]. A novel technique based on classify the recloser-fuse coordination status at fault condition 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 case where no action is required [11]. 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 multi-population method and the influence of improper genetic parameters can be greatly decreased and premature convergence can be overcome effectively [12]. 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 [13]. Optimal number and location of recloser to improve reliability of feeders using genetic algorithm has performed. The proposed method enjoys the simplicity of configure duration, accuracy of the results and reduction of the time consuming. The obtained results also show the applicability of the algorithm [14]. the effects of demand response programs especially direct load control on system and nodal reliability of a deregulated power system using direct load control and economic load model [15]. A two-stage Placement proposed without involving random variable such as failure rates and interruption durations of the system. However, all contingencies are given the same weight and no reliability index is analysed [16]. A mixed integer linear programming (MILP) and CPLEX used to solve the problem. They also presented a sensitivity analysis on the effect of interruption cost (customer damage function) number of devices to be placed, customer type and load density [17]. An Evolutionary Intelligent Method for solving the problem of location and optimized size of *DG* resources with multiple objectives [18]. The difference between the operations of circuit breaker and sectionalizer has considered [19].

Placement solutions in the above papers typically used the observed sample means for random variables such as failure rates and interruption durations, without considering load models. In this paper optimal recloser number and placement with load model consideration has been done to enhance reliability indices and teaching learning based algorithm proposed as an efficient method to solve discrete problem. Eventually, simulation has been carried out on IEEE 69-bus radial distribution system.

All the simulations are carried out in MATLAB software. The rest of the paper is organized as follows: section 2 discusses finding optimal recloser placement. It has been formulated with proposed function which is consisted different reliability indices. Load model and forward-backward load flow have discussed in Section 3 and 4, respectively. Section 5 represents TLBO formulation and solving method. The comparison between different load model effectiveness has shown in Section 6 and finally concluding remarks are drawn in section 7.

2. Optimal Recloser Placement

The reasons for distribution companies to install recloser are for increasing system reliability. Studies have been done in recloser placement usually include energy not supplied as an objective function. The indices of reliability are categoried as customer indices and load indices. Since taking on index may change other indices, therefore in this article and objective function based on the sum of the weighted reliability indices have been proposed. The objective functions in this paper, according to following relationship.

$$OF = W_{SAIFI}\frac{SAIFI}{SAIFI_T} + W_{SAIDI}\frac{SAIDI}{SAIDI_T} + W_{AENS}\frac{AENS}{AENS_T} \quad (1)$$

where

$$AENS = \frac{\sum_{i=1}^{n} P_i.U_i}{\sum_{i=1}^{n} N_i} \quad (2)$$

$$SAIFI = \frac{\sum_{i=1}^{n} \lambda_i.N_i}{\sum_{i=1}^{n} N_i} \quad (3)$$

$$SAIDI = \frac{\sum_{i=1}^{n} U_i.N_i}{\sum_{i=1}^{n} N_i} \quad (4)$$

N_i is the number of customer at i^{th} load point, U_i is interruption duration at i^{th} load point, P_i is average load at i^{th} load point, W_x is weight coefficient and X_T is target value for reliability indices. In this article, W_x values for AENS, SAIFI, and SAIDI are 0.33, 0.33, and 0.34. In addition for target values are 350, 10, and 100, respectively.
With constraints:
$n \leq Nmax$
n: number of reclosers
Nmax: maximum number of reclosers

With a simple example, the method of calculation of the indicators described. Figure 1 shows a sample radial distribution system of four lines A, B, C and D with four load points 1, 2, 3, and 4. Hypothetical reclosers R1, R2, R3 have been placed in appropriate locations. If X_i=0, it means the absence and X_i=1, means presence of recloser. Unavailability and failure rate of load point can be calculated in the following approach.

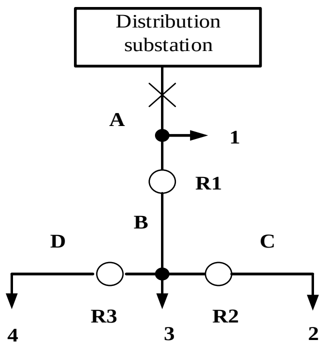

Figure 1. Sample radial distribution system

First, unavailability to each of lines *A*, *B*, *C,* and *D* can be calculated.

According to the network structure shown in Figure 1. Load point 1, in the following scenarios are without electricity:

$$U_A = \lambda_A r_A \qquad U_B = \lambda_B r_B$$
$$U_C = \lambda_C r_C \qquad U_D = \lambda_D r_D \quad (5)$$

1) A fault on the line A.
2) A fault on the line B in the absence of R_1 (X_1'=1 or X_1=0).
3) A fault on the line C in the absence of R_1, R_2 (X_1'. X_2'=1).
4) A fault on the line D in the absence of R_1, R_3 (X_1'. X_3'=1).

Therefore load point 1 unavailability can be formulated in (6).

$$u_1 = U_A + U_B \cdot x_1' + U_C \cdot x_1' \cdot x_2' + U_D \cdot x_1' \cdot x_3' \quad (6)$$

In this equation X' is complimentary to X (X' = 1–X).
Similarly, unavailability of load points 2, 3, and 4 can be formulated as equations (7-9).

$$u_2 = U_A + U_B + U_C + U_D \cdot x_3' \quad (7)$$

$$u_3 = U_A + U_B + U_C \cdot x_2' + U_D \cdot x_3' \quad (8)$$

$$u_4 = U_A + U_B + U_C \cdot x_2' + U_D \quad (9)$$

Failure rate for load point 1 to 4 can be accessed by replacing with line unavailability. Thus, reliability indices can be calculated.

3. Load Model

In this paper different voltage-dependent load models scenarios are be investigated. Practical voltage-dependent load models, i.e., residential, industrial and commercial have been adopted for investigations. To formulate the problem equation (10) and (11) will be used.

$$P_i = P_{oi} V_i^{\alpha} \quad (10)$$

$$Q_i = Q_{oi} V_i^{\beta} \quad (11)$$

P_i and Q_i are the real and reactive power at i^{th} load bus, respectively. P_{oi} and Q_{oi} are the real and reactive operating points at i^{th} load bus. V_i is i^{th} voltage bus and α and β are real and reactive power exponents. In the constant power model conventionally used in power flow studies, $\alpha = \beta = 0$ is assumed. The values of the real and reactive exponents used in the present work for industrial, residential, and commercial loads are given in Table 1 [20].

Table 1. Results for Pareto Reconfiguration with two Objectives

Load Type	α	β
Constant	0	0
Industrial	0.18	6
Residential	0.92	4.0
Commercial	1.51	3.4

In practice, loads are mixtures of different load types, depending on the nature of the area being supplied.

Therefore, a load class mix of residential, industrial, and commercial loads is to be investigated, too [21].

4. Forward-Bakwaerd Load Flow

Gauss-seidel and newton-raphson are two conventional method used to calculate the load flow in power system. Lack of proper performance becomes clear when encounter with load unbalances in distribution network, radial structure and high proportion of resistance and reactance on the lines.

Other method is widely used named forward-backward. This method is based on the repeated stages that each iteration consists of two steps:

In the first stage all the branches current are calculated (backward step) and in the second stage, with calculated branches current and line impedance, buses voltage are obtained (forward step). Then buses voltage and branches current value will be updated [22].

5. Teaching-Learning-Based algorithm

The basis of this algorithm is based on the teaching of a teacher in the classroom [23]. The teacher in the classroom plays a major role in student learning and better student learning depends on the teacher speech. In addition to the effects of teacher, review texts between students themselves are also leading to learn their studies better. This idea forms the basis of TLBO to solve optimization problem.

TLBO algorithm divided into two parts. The first part consists of teacher phase. The second part consists of learner phase.

The teacher phase means learning from the teacher and the learner phase means learning through the interaction between learners.

5.1. Teacher Phase

A good teacher brings his or her learners up to his or her level in terms of knowledge. But in practice this is not possible and a teacher can only move the mean of a class up to some extent depending on the capability of the class. This follows a random process depending on many factors.

$$X_{new,D} = X_{old,D} + r(X_{teacher,D} - T_F M_D) \tag{12}$$

D index indicates the number of course (variable problem), $X_{old,D}$ old member, still have to increase their knowledge of the teacher's teach and includes 1*D vector which gets results related to any specific topics or lessons. r is a random number in the range [0,1]. $X_{teacher,D}$ is the best member of population in iterations that tries for the average of the class (population) to its position. The value of T_F can be either 1 or 2 which is again a heuristic step and decided randomly with equal probability as T_F= round[1+rand (0,1){2-1}]. M_D is 1*D vector that includes the mean values for each subject in class. $X_{new,D}$ if compared to the old members and improved will be accepted.

5.2. Student Phase

Learners increase their knowledge by two different means. One through input from the teacher and other through interaction between themselves. A learner interacts randomly with other learners with the help of group discussions, presentations, formal communications and etc. A learner learns something new if the other learner has more knowledge than him or her. Learner modification is expressed as

For i=1: P_n

Randomly select another learner X_j, such that $i \neq j$.

$$\begin{aligned}
&if\ f(X_i) < f(X_j)\\
&X_{new,i} = X_{old,i} + r_i\left(X_i - X_j\right)\\
&Else\\
&X_{new,i} = X_{old,i} + r_i\left(X_j - X_i\right)\\
&Endif\\
&Endfor
\end{aligned} \tag{13}$$

Accept X_{new} if it gives a better function value. The flow chart for TLBO method is given in Figure 2.

6. Simulation Results

In order to investigate the performance of the proposed approach, the IEEE 69-bus radial distribution test system is utilized in this paper. Figure 3 shows the single line diagram of the test system. The total amounts of theactive and reactive loads of the system are 3.8019 MW and 2.6941 MVAr, respectively.

The forward-backward load flow is done due to obtained voltage and then power in each bus. In next step with load model consideration and without that, simulation will be run. The process is repeated by 100 iterations and 20 populations. Simulation results for IEEE 69-bus [24], are indicated in Table 2. The system data are given in Table 3.

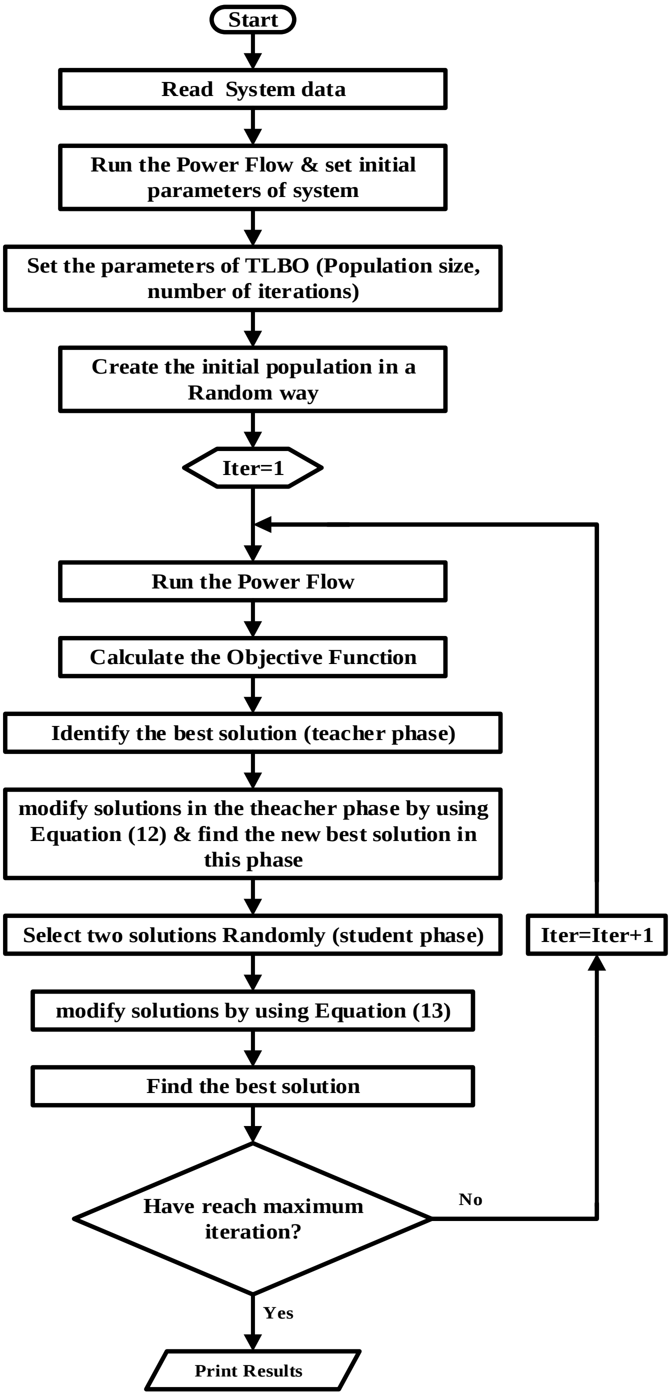

Figure 2. Flow chart showing the working of TLBO algorithm

It was performed for different aspects of recloser placement and termination condition was selected as the objective function in each stage not much different than the previous stage. Stop condition is formulated as follows:

$$\eta = [\frac{\alpha_0 - \alpha_i}{\alpha_0 - \alpha_{min}}] \times 100 \qquad (12)$$

η is improvement percentage with i recloser, α_0 is objective function when no recloser in network. α_i is minimum objective function value when *i* recloser in network, α_{min} is minimum objective value (when all lines have recloser).

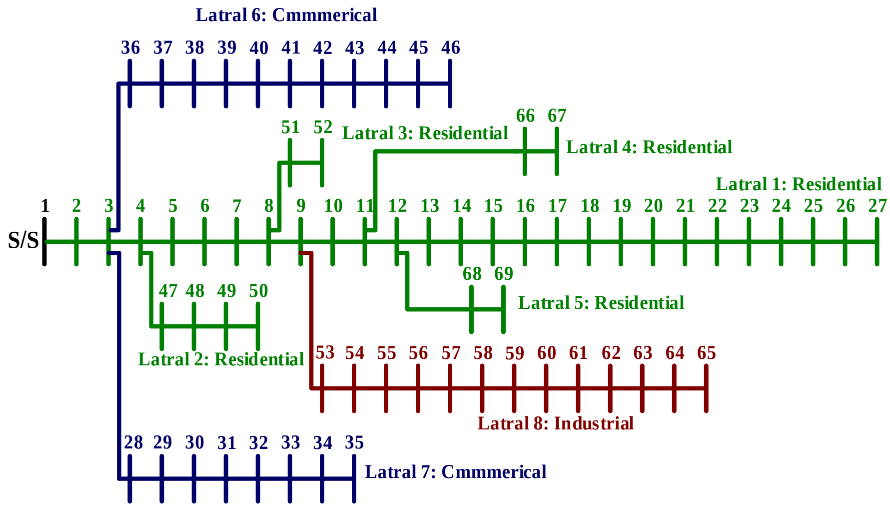

Figure 3. Single line diagram of 69-bus distribution test system

Table 2. Optimal placement and OF Value for 69-bus Distribution Test System

Load Model	Recloser Number	Optimal Placement	OF Value	η(%)
Constant	0	-	0.56167	0
	1	8-9	0.26453	67.43
	2	26-27, 61-62	0.20664	77.34
	3	9-10, 3-36, 4-47	0.16345	86.75
	4	34-35, 42-43, 9-53, 12-68	0.14009	91.84
	5	7-8, 14-15, 9-53, 12-68, 68-69	0.13371	93.23
	6	7-8, 16-17, 21-22, 28-29, 9-53, 12-68	0.12636	94.83
	7	9-10, 12-13, 29-30, 3-36, 36-37, 53-54, 6-65	0.12085	96.03
	8	5-6, 12-13, 34-35, 36-37, 49-50, 8-51, 56-57, 58-59	0.11580	97.13
	9	2-3, 6-7, 12-13, 14-15, 17-18, 25-26, 42-43, 53-54, 58-59	0.11098	98.18
	10	3-4, 6-7, 8-9, 10-11, 16-17, 22-23, 9-53, 56-57, 57-58, 61-62	0.10823	98.78
	68	All lines	0.10263	100
Composite	0	-	0.56162	0
	1	10-11	0.31253	54.27
	2	10-11, 15-16	0.26135	65.42
	3	3-4, 9-10, 40-41	0.22036	74.35
	4	3-28, 29-30, 3-36, 64-65	0.18226	82.65
	5	25-26, 36-37, 40-41, 56-57, 59-60	0.16120	87.74
	6	3-4, 10-11, 40-41, 42-43, 59-60, 62-63	0.14141	91.55
	7	5-6, 9-10, 17-18, 18-19, 24-25, 44-45, 48-49	0.12865	94.33
	8	9-10, 18-19, 19-20, 20-21, 3-36, 36-37, 58-59, 11-66	0.12131	95.93
	9	20-21, 22-23, 34-35, 38-39, 43-44, 4-47, 53-54, 58-59, 62-63	0.11489	97.33
	10	6-7, 14-15, 3-28, 30-31, 38-39, 4-47, 51-52, 9-53, 58-59, 68-69	0.1102	98.35
	11	4-5, 9-10, 20-21, 23-24, 30-31, 37-38, 40-41, 49-50, 55-56, 61-62, 64-65	0.10836	98.75
	68	All lines	0.10262	100

Table 3. 69-bus test system data System

Br. no	S. no	R. no	Length (km)	λ (f/yr)	r (h)	Number of customer	Load type
1	1	2	0.8	0.065	5	200	0
2	2	3	0.7	0.065	5	200	2
3	3	4	0.6	0.065	5	1	2
4	4	5	0.7	0.065	5	1	2
5	5	6	0.6	0.065	5	10	2
6	6	7	0.6	0.065	5	10	2
7	7	8	0.6	0.065	5	210	2
8	8	9	0.8	0.065	5	210	2
9	9	10	0.6	0.065	5	3	2
10	10	11	0.8	0.065	5	3	2
11	11	12	0.8	0.065	5	1	2
12	12	13	0.7	0.065	5	1	2
13	13	14	0.7	0.065	5	200	2
14	14	15	0.6	0.065	5	200	2
15	15	16	0.8	0.065	5	1	2
16	16	17	0.6	0.065	5	1	2
17	17	18	0.6	0.065	5	10	2
18	18	19	0.7	0.065	5	10	2
19	19	20	0.6	0.065	5	210	2
20	20	21	0.7	0.065	5	210	2
21	21	22	0.6	0.065	5	3	2
22	22	23	0.8	0.065	5	3	2
23	23	24	0.6	0.065	5	1	2
24	24	25	0.6	0.065	5	1	2
25	25	26	0.8	0.065	5	200	2
26	26	27	0.7	0.065	5	200	2
27	3	28	.6	0.065	5	1	3
28	28	29	0.6	0.065	5	1	3
29	29	30	0.8	0.065	5	10	3
30	30	31	0.7	0.065	5	10	3
31	31	32	0.7	0.065	5	210	3
32	32	33	0.7	0.065	5	210	3
33	33	34	0.6	0.065	5	3	3
34	34	35	0.8	0.065	5	3	3
35	35	36	0.6	0.065	5	1	3
36	36	37	0.7	0.065	5	1	3
37	37	38	0.6	0.065	5	200	3
38	38	39	0.7	0.065	5	200	3
39	39	40	0.8	0.065	5	1	3
40	40	41	0.8	0.065	5	1	3
41	41	42	0.6	0.065	5	10	3
42	42	43	0.8	0.065	5	10	3
43	43	44	0.7	0.065	5	210	3
44	44	45	0.8	0.065	5	210	3
45	45	46	0.6	0.065	5	3	3
46	4	47	0.6	0.065	5	3	3
47	47	48	0.7	0.065	5	1	2
48	48	49	0.6	0.065	5	1	2
49	49	50	0.8	0.065	5	200	2
50	8	51	0.8	0.065	5	200	2
51	51	52	0.6	0.065	5	1	2
52	9	53	0.8	0.065	5	1	2
53	53	54	0.8	0.065	5	10	1
54	54	55	0.7	0.065	5	10	1
55	55	56	0.6	0.065	5	210	1
56	56	57	0.8	0.065	5	210	1
57	57	58	0.6	0.065	5	3	1
58	58	59	0.8	0.065	5	3	1
59	59	60	0.7	0.065	5	1	1
60	60	61	0.6	0.065	5	200	1
61	61	62	0.8	0.065	5	200	1
62	62	63	0.6	0.065	5	1	1
63	63	64	0.6	0.065	5	210	1
64	64	65	0.7	0.065	5	210	1
65	11	66	0.7	0.065	5	210	1
66	66	67	0.6	0.065	5	210	2
67	12	68	0.6	0.065	5	210	2
68	68	69	0.7	0.065	5	210	2

Note: N: number of customer, Load type: Constant=0, Industrial=1, Residential=2, Commercial=3

It can be seen with Constant load the difference between 9 and 10 reclosers less than 1%. So, the best number for recloser placement of 69-bus distribution test system is 9. In addition with load model consideration the optimal recloser number and placement have been changed to 10. Recloser number and optimal placement have been shown in Table 2. According to the results of Table 2, it can be noted that recloser number and placement changed with load model consideration.

7. Conclusion

A novel method based on TLBO algorithm for optimal number and placement of recloser was proposed in this paper. The main purpose of this study is reliability improvement. Also by using an objective function with impact on reliability indices, the best locations and numbers of reclosers are selected.

Reclosers have played a fundamental role in improving the reliability of distribution system. Therefore, it is essential to determine the optimum number and location of reclosers due to improve network reliability. Simulation results show that as the number of reclosers increased, network reliability improved. However, distribution companies should also pay higher cost as well. Several parameters can determine the optimum number of reclosers. Here, the difference between two steps in objective function value should be less than 1%. If the difference in objective function is less than 1%, this step will select as the optimal number and location of reclosers, besides, it can reveal that load model change the optimal number and location of reclosers.

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