Multi-objective Binary Particle Swarm Optimization Algorithm for Optimal Distribution System reconfiguration

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***Abstract*—One of the salient features of protection system in smart grid is to reconfigure the network automatically with a view to insure power system reliability. This paper introduces a binary particle swarm optimizer (BPSO) based procedure for handling the network reconfiguration (NR) problem. Two objectives are taken into consideration; the first strives for reducing the system losses while the second objective function improves the voltage profile. A multi-objective framework is developed to achieve these objectives simultaneously. The proposed procedure seeks about the optimal tie switches positions and provides the minimum number of sectionalizing switches in the branches to reduce the system losses. Depending on distribution feeder operations, the distribution reconfiguration is done as binary arrangement combination of switches. The performance of distribution networks is carried out using MATLAB programming to check the effectiveness of BPSO algorithm. Numerical results are presented to explain the feasibility and the validation of the proposed procedure through the application on three standard systems called 33, 69 and 119 IEEE node systems. The obtained results using the BPSO technique are matched with various methods in the literature to manifest the efficacy of the proposed procedure.**

Keywords: Reconfiguration of distribution networks, binary particle swarm optimizer, loss minimization, voltage improvement

List of symbols:

N	overall number of branches
I_j	current of branch j.
R_j	resistance of branch j.
ω_1 and ω_2	weighting factors
V_{bus}	bus voltage magnitude.
V_{rating}	nominal voltage (1 p.u.).
V_{max}	maximum voltage (1.05 p.u.).
V_{min}	minimum voltage (0.9 p.u.).
I_j	magnitude of the feeder's branch current.
I_{max}	maximum value of the current.
g	topological structure in accordance with NR.
G	group of possible topological structures.
P_{best} & G_{best}	persolal and global bests .
V_{id}^{new}	new value of the particle speed.
W	inertia weight.
V_{id}	velocity for the particle i.
c_1, c_2	acceleration factors ($c_1=c_2=2$).
R_1 and R_2	random numbers within range [0-1].
x_{id}	*position of the particle i.*
$S(V_d)$	*sigmoid function for the particle speed v.*

I. Introduction

Electrical power distribution system (EPDS) is a serious sector in power systems. It is generally structured with radial configuration for functional coordinate of its protective devices. EPDSs receive the electric power from the transmission or sub-transmission systems and transfer it directly to consumer centers [1]-[3]. Currently, a great amount of electrical energy produced from the generation companies is lost within these mediator networks. Nearly 40 % of these power losses occur on the distribution networks [4].

There is lot of methods for the reduction of the active power losses in EPDSs like network reconductoring, distribution transformer locating and sizing, automatic voltage booster, Var compensation, high-efficient transformer, high voltage upgrading in EPDSs and reconfiguration of them. Two kinds of switches are subsisted in EPDS operation, which are purposed for both restoration and NR management [1]-[3], [5].

The distribution systems operation in a radial configuration and used alternate feeds by using tie switches should be operated to maintain power to the customers. The practical aspects of EPDS should be taken into account as well, for implementing the NR. The system reconfiguration is known as the procedure of varying the status of the same switches in EPDS for enhancing the system performance and mainly for loss reduction [3], [4].

There are various methods that have been performed searching for the optimal NR in EPDS. In Ref. [3], a modified teaching-learning-based optimizer (MTLBO) has been carried out for handling the problem of NR in EPDS with intent for minimizing the operational costs and maximizing the reliability of the system. In [4], a modified version of PSO has been presented for solving the NR in EPDS for loss reduction, but this study was limited to a small search space by implementation for just a small system of IEEE 33-node.

The Tabu search (TS) algorithm has been carried out for solving the NR problem in [5] and [6]. In Ref. [7], the NR problem has been described via the branch exchanging method that was capable of changing the status of either tie or sectional switches with a view to reduce the system power losses and load balancing. Reference [8] presented a multiple objectives fuzzy based adoption of evolutionary for power losses and minimum node voltage deviations. In Ref. [9], the NR problem and their effects on the topological structures and the allocations of the losses have been discussed. In Ref. [10], the stability problem of nodes voltage has been incorporated in EPDSs through NR problem. Reference [11] characterized an adaptive PSO for handling the NR problem in EPDS in the seeking of minimizing the system losses as a mono objective task. A binary variant of PSO has been applied for the same purpose in Ref. [12], but, their scalability and validity haven't been clarified since small scale EPDSs of 16- and 33-bus systems were utilized. Reference [13] presented harmony search algorithm for reconfiguring large-scale EPDSs to reduce the system losses.

In Ref. [14], a backtracking search algorithm has been adopted considering the NR problem by reducing the total costs related to the system losses. Reference [15] presented the dragonfly algorithm to the NR problem. In addition, the artificial immune optimizer has been executed for reducing the system losses and improving the reliability indicator through the application of the graph theory [16]. In [17] and [18], the genetic algorithm was applied for reconfiguration of electrical distribution network. In [19], another method called an adaptive cuckoo search was proposed for optimal distribution NR with existence of distributed units of power generation. Evaluation of the NR in distribution systems in the existence of renewable power resources was presented in [20]-[22]. Otherwise, fireworks optimization technique has been developed for solving the distributed system reconfiguration in [22]. In [23], the simulated annealing immune algorithm was integrated to solve the considered NR problem for power loss minimization. The ant colony optimizer was applied for network reconfiguration in EPDSs in [24].

The artificial intelligent optimization algorithm, PSO, is introduced by Kennedy and Eberhart in [24]. Sample applications are reported in [25]-[29]. In these applications varied natures real coded and binary coded PSO were developed.

This paper proposes a NR procedure for supporting the performance of EPDS using BPSO algorithm. The proposed procedure can produce an optimum configuration in network to reduce the system losses and to ameliorate the voltage profile and increasing the power factor. Also, the BPSO improves the convergence characteristic with small computational time compared to the other methods. Numerical results are presented to explain the feasibility and the validation of the proposed procedure through the application on three standard systems called 33, 69 and 119 IEEE node systems. The obtained results using the BPSO technique are matched with various methods in the literature to manifest the efficacy of the proposed procedure.

II. FORMULATION OF THE NR PROBLEM

This paper objective is to introduce a proposed procedure using the binary coding particle swarm optimization in system reconfiguration for reducing the system losses in EPDSs.

A. Objective Functions

The main objective functions for network reconfiguration is to minimize the system losses and improving the voltage profile considering the voltage and reactive power limits [22] as:

$$f_1 = Minpower_{losses} = \sum_{j=1}^{N} (\mathrm{I}_j^2) R_j \tag{1}$$

$$f_2 : \min VD = \sum_{i=1}^{N} \frac{\left| v_{rating} - v_{bus} \right|}{v_{rating}} \tag{2}$$

$$F = \omega_1 f_1 + \omega_2 f_2 \tag{3}$$

Where, $\omega_1 + \omega_2 = 1$ (4)

B. The System Constraints

The bus voltage magnitude should be with the following limits:

$$V_{\min} \le V_{bus} \le V_{\max} \tag{5}$$

The current must be less or equal to the maximum current as:

$$I_j \le I_{\max} \tag{6}$$

The system must be radial under normal conditions according to this equation:

$$g \in G \tag{7}$$

III. PROPOSED OPTIMIZATION METHOD

Every PSO particle has a best value calculated by the considered fitness function which is required to be evaluated for each particle in the population. Every one changed the area of searching depending on two values" P_{best} & G_{best}" in each iteration. Particles change their velocity and their position when the best value of P_{best} and G_{best} are obtained depending on Eq. (8) and Eq. (9). The solution is checked at each iteration and these changes in velocities and positions are updated until the best particle is obtained and the constrains are satisfied.

$$V_{id}^{new} = WV_{id} + C_1 * rand(1) * (P_{best} - X_{id}) + C_2 * rand(2) * (G_{best} - X_{id}) \tag{8}$$

$$X_{id}^{new} = X_{id} + V_{id}^{new} \tag{9}$$

The PSO has applied to optimize different continuous function optimization problems successfully. For solving a discrete function optimization problem, a binary version of PSO is introduced called BPSO. The main PSO is changed for solving discrete problem by using probability of using binary space. The value of position is updated in the next equations for each bit of a particle according to these equations:

$$s(v_d) = \frac{1}{1 + e^{-v_d}} \tag{10}$$

$$x_{id}^{new} = \begin{cases} 1 & , if rand \prec s(v_d) \\ 0 & otherwise \end{cases} \tag{11}$$

The sigmoid transformation for the component of velocity is used to squash the velocities in between [0, 1] and make the values of component of the particles locations to be 0's or 1's using Eq. (11). In distribution network reconfiguration problem, the value (1's) means closed switch and while (0's) means open switch. The velocity for each search space is calculated by closing the tie line and start open the line section, respectively, one by one. Then if the velocity >0.5 the individual P_{best} will be update for the test or stop, and check another particle if the velocity <0.5 G_{best} will be calculated and the velocity for all particle is calculated after checking all dimension of particle and the P_{best} is updated for each one.

Fig. 1 displays the flowchart of the proposed BPSO method for handling the distribution system reconfiguration.

IV. APPLICAIONS

A. *Test Distribution Systems*

In this section, three EPDSs are considered. The first one is the IEEE 33-node test system that is shown in Fig. 2.a. This system contains 37 branches, 32 sectionalizing switches which are in a regular closed status and 5 tie line switches which are in a regular open status before any reconfiguration. The initial tie lines switches of the system are from bus 33 to 37. The second test system is the IEEE 69-node test system that is depicted in Fig. 2.b. This system contains 73 branches, 68 normally closed switches. Its line data are given in [25]. The last test system is the IEEE 119-node test system. It is considered a large-scale EPDS. This system contains 15 tie line switches and other 118 sectionalizing ones. Its data of lines and loads are shown in [31]. Tables 1-3 present the essential loops for IEEE 33- , 69-, 119-bus distribution systems, respectively. From these tables, there are 5 essential loops in the first and second test systems while the third one has 15 essential loops.

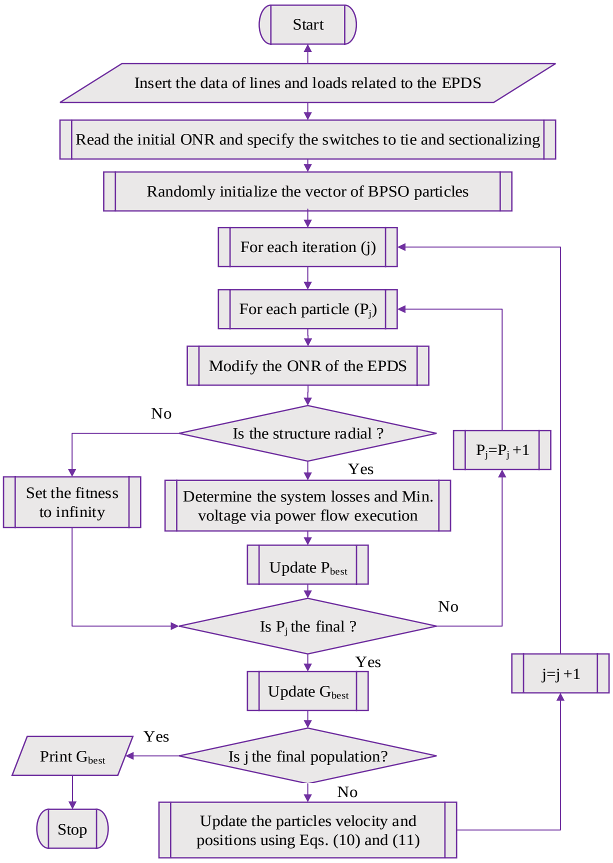


Fig. 1. Proposed BPSO's flowchart of ONR in distribution networks

TABLE I. ESSENTIAL LOOPS IN IEEE 33-NODE EPDS

loop	switches
1	S2-S3-S4-S5-S6-S7-S18-S19-S20-S33
2	S9-S10-S11-S12-S13-S14-S34
3	S2-S3-S4-S5-S6-S7-S8-S9-S10-S11-S18-S19-S20-S21-S35
4	S6-S7-S8-S9-S10-S11-S12-S13-S14-S15-S16-S17-S25-S26-S27-S28-S29-S30-S31-S32-S36
5	S3-S4-S5-S22-S23-S24-S25-S26-S27-S28-S37

S refers to a sectionalizing line switch

TABLE II. ESSENTIAL LOOPS IN IEEE 69-NODE EPDS

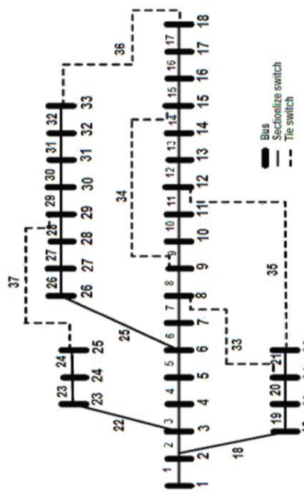
loops	switches
1	S3-S4-S5-S6-S7-S8-S9-S10-S35-S36-S38-S39-S40-S41-S42-S69
2	S13-S14-S15-S16-S17-S18-S19-S20-S70
3	S3-S4-S5-S6-S7-S8-S9-S10-S11-S12-S13-S14-S35-S36-S37-S38-S39-S40-S41-S42-S43-S44-S45-S71
4	S4-S5-S6-S7-S8-S46-S47-S48-S49-S52-S53-S54-S55-S56-S57-S58-S72
5	S9-S10-S11-S12-S13-S14-S15-S16-S17-S18-S19-S20-S21-S22-S23-S24-S25-S26-S52-S53-S54-S55-S56-S57-S58-S59-S60-S61-S62-S63-S64-S73

TABLE III. ESSENTIAL LOOPS IN IEEE 119-NODE EPDS

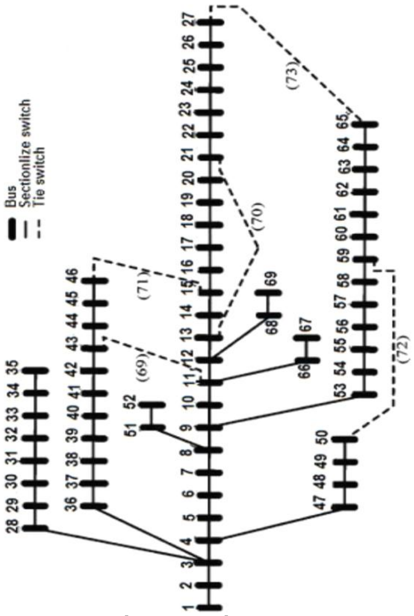
loops	switches
1	S3-S9-S10-S17-S18-S19-S20-S21-S22-S23-S24-S25-S26-S27-S28-S37-S38-S39-S40-S41-S42-S43-S44-S45-S118
2	S11-S12-S13-S14-S15-S16-S17-S18-S19-S20-S21-S22-S23-S24-S25-S26-S119
3	S3-S4-S5-S6-S7-S8-S9-S10-S17-S18-S19-S20-S21-S22-S23-S120
4	S29-S30-S31-S32-S33-S34-S37-S38-S39-S40-S41-S42-S46-S47-S48-S49-S0-S51-S52-S53-S121
5	S29-S30-S31-S32-S33-S34-S37-S46-S47-S48-S49-S50-S51-S52-S53-S54-S55-S56-S57-S58-S59-S60-S61-S122
6	S29-S35-S36-S54-S55-S56-S57-S58-S59-S60-S61-S123
7	S4-S5-S6-S7-S8-S27-S28-S37-S38-S39-S124
8	S1-S3-S27-S28-S54-S55-S56-S57-S62-S63-S64-S88-S89-S90-S95-S125
9	S65-S66-S67-S68-S69-S70-S71-S72-S88-S89-S90-S126
10	S64-S65-S66-S67-S68-S69-S70-S71-S72-S73-S74-S77-S78-S85-S86-S87-S127
11	S65-S66-S67-S68-S69-S70-S71-S72-S73-S74-S75-S76-S88-S89-S90-S95-S 96-S97-S98-S128
12	S62-S63-S77-S78-S79-S80-S81-S82-S99-S100-S101-S102-S103-S104-S 105-S106-S107-S129
13	S62-S63-S77-S78-S85-S99-S100-S101-S102-S103-S104-S130
14	S100-S101-S102-S103-S104-S105-S106-S107-S108-S113-S114-S116-S117-S131
15	S3-S9-S10-S17-S18-S19-S20-S21-S22-S23-S24-S27-S28-S29-S30-S31-S32-S 33-S34-S132

B. *Results and comments*

For minimizing the power losses, the binary particle swarm optimizer (BPSO) is tested through the IEEE 33-, 69- and 119-node EPDSs. For Case 1, BPSO reduces the system losses in the IEEE 33-node EPDS from initially 208.5 kW to 124.7 kW with saving of 40%. Similar trend is observed for the IEEE 69-node EPDS as losses have been decreased from 225.004 kW to 99.6216 kW with saving of 56%. Also, in the IEEE 119-node EPDS, the losses are decreased from 1298.09 kW to 676.88 kW savings 621.21 kW (48%) of power losses.



a. IEEE 33- bus distribution system



b. IEEE 69-bus system

Fig. 2. Single line diagram of tested systems

For the second case (Case 2), the proposed BPSO makes a significant improvement in voltage profile as the minimum voltage after NR implementation rises from 0.91 p.u. to 0.936 p.u. for IEEE 33-node EPDS, rises from 0.909 p.u to 0.949 p.u for IEEE 69-node EPDS, and rises from 0.868 p.u to 0.9335 p.u for IEEE 119- node EPDS. For Case 3, notable improvements are achieved for voltage profile and system losses for the three tested EPDSs. The power losses are reduced by 34%, 44% and 66% for the IEEE 33-node, 66-node and 119- node EPDSs. Tables 4-6 record the three tested system performance of BPSO for Cases 1-3, respectively. The bus bar voltages of proposed BPSO have significant improvement for the test systems as shown in Fig. 3.

C. Results and comments

Tables 7-9 show the NR results for the tested IEEE systems, in terms of the tie switches combination, the related percentage of losses reduction (Red_{Loss}), and the minimum voltage (V_{min}), using different optimization methods for Cases 1-3, respectively. The proposed BPSO drives the greatest reduction level by 40.18 % compared with other method. The compared results of NR implementation for IEEE 69-node EPDS illustrate that the proposed BPSO leads to the highest reduction level by 56 % compared with other method. The compared results of NR implementation for IEEE 119-node EPDS illustrate that the proposed BPSO finds the highest reduction level by 47.86 % compared with other methods.

TABLE IV. BPSO PERFORMANCE OF TESTED DISTRIBUTION SYSTEMS FOR CASE 1

Element	*System*	*33-bus*	*69-bus*	*119-bus*
Switches	*Before*	33,34,35 36, 37	69,70,71 ,72,73	119,120,121,122 123,124,125,126 ,127,128,129,130 131,132,133
	After	4, 10, 12, 24 ,30	14, 58, 61 , 69 ,70	12, 21, 33, 42, 44, 52, 59, 72, 78 , 90 ,96
OF: Losses (kW)	*Before*	208.5	225	1298.09
	After	124.7	99	676.88
Vd p.u	*Before*	0.9108	0.9092	0.9131
	After	0.9413	0.9495	0.9323

TABLE V. BPSO PERFORMANCE OF TESTED DISTRIBUTION SYSTEMS FOR CASE 2

Element	*System*	*33-bus*	*69-bus*	*119-bus*
Switches	*Before*	33,34,35 36, 37	69,70,71 ,72,73	119,120,121,122 123,124,125,126 ,127,128,129,130 131,132,133
	After	7, 11, 14, 28,,32	11, 12, S57, 58 ,71	23, 27, 43, 53, 62, 72, 75, 123, 125, 126 129,133
Min. Vd p.	*Before*	0.91075	0.909	0.8688
	After	0.95379	0.9495	0.9335
Losses (kW)	*Before*	208.4592	224.9804	294.3
	After	141.6346	198.5952	865.87

TABLE VI. BPSO PERFORMANCE OF TESTED-BUS DISTRIBUTION SYSTEMS FOR CASE3

Element	*System*	*33-bus*	*69-bus*	*119-bus*
Switches	*Before*	33,34,35 36, 37	69,70,71 ,72,73	119,120,121,122 123,124,125,126 ,127,128,129,130 131,132,133
	After	7, 9, 14, 32,37	14, 55, 61, 69,70	24, 26, 35, 40, 43,51, 59,72, 75, 96, 110, 122, 130 ,131
minimum voltage p.u	*Before*	0.91075	0.9094	0.8667
	After	0.94234	0.943	0.9323
Losses (kW)	*Before*	208.5	225	1298
	After	138.9275	98.93	856.8
Loss reduction %		34%	44%	66%

TABLE VII. COMPARATIVE RESULTS FOR NR FOR CASE 1

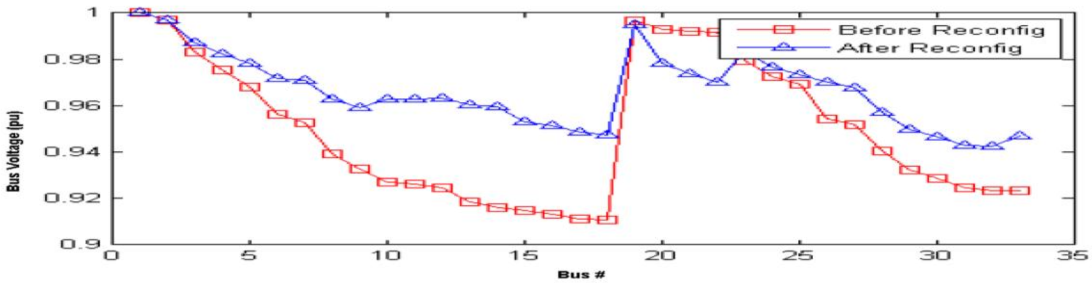
IEEE 33-node EPDS			***IEEE 69-node EPDS***			***IEEE 119-node EPDS***		
Method	***Tie switches***	***Red_{Loss}***	***Method***	***Tie switches***	***Red_{Loss}***	***Method***	***Tie switches***	***Red_{Loss}***
EP [8]	7,14,9,32,37	33.76%	***DFA [15]***	69,70,12,58,61	55.64%	**TS [5]**	43,27,23,52,49,62,40,126, 74,72,77,83,131,110,33	31.7%
APSO [11]	7,9,14,32,37	*31.15%*	***GA [17]***	69,70,14,53,61	54.08%	**RGA [18]**	43,27,23,52,49,62,40, 126, 74, 73, 77, 83, 131, 110, 33	32.2%
DFA [15]	11,14,7,31,28	*34.62%*	***RGA [18]***	69,17,13,55,61	55.42%	**AACO**	24,27,35,40,43,52,59,72, 75, 96, 98, 110, 123, 130,131	33.5%
IGA[32]	7,9,14,32,37	*31.1%*	***IGA[32]***	10,14,58,63,70	53.53%	**MHA[33]**	43,27,24,52,123,59,40,96,75,72,98, 130,131,110,35	33.5%
BPSO	4,10,12,24,30	*40.18%*	***BPSO***	14,58,61,69,70	56%	**BPSO**	12,21,33,42,44,52,59,72,78, 90, 96, 103, 105, 109, 124	47.86%

TABLE VIII. COMPARATIVE RESULTS FOR NR FOR CASE 2

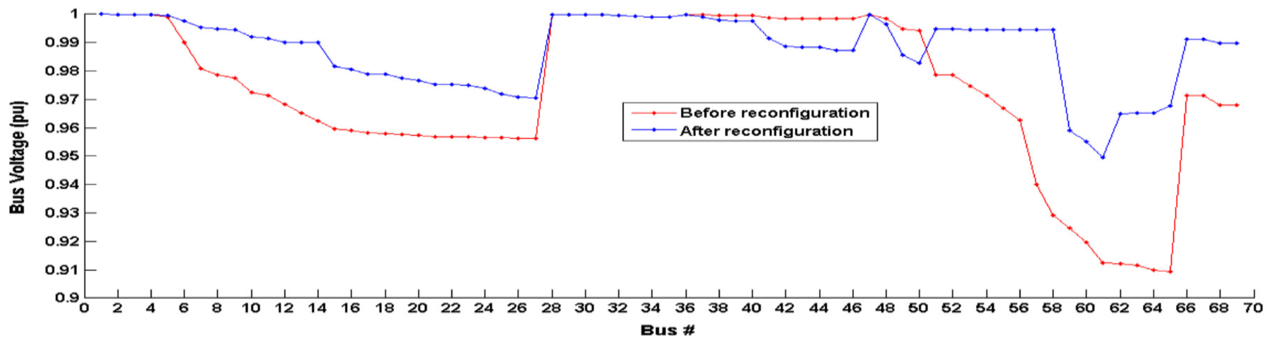
IEEE 33- node EPDS			*IEEE 119- node EPDS*			*IEEE 69- node EPDS*		
Method	***Tie switches***	***V_{min} (p.u)***	***method***	***Tie switches***	***V_{min} (p.u)***	***method***	***Tie switches***	***V_{min} (p.u)***
initial	33,34,35,36,37	0.91075	***initial***	118,119,120,121,122,123,124,125, 126,127,128,129,130,131,132	0.8688	***initial***	69,70,71,72,73	0.909
FWA [23]	7,9,14,28,32	0.9423	**GA [17]**	43,120,24,51,49,62,40,126,74,73,77, 83,31,110,35	0.9321	**HAS[12]**	13,18,56,61,69	0.9428
RGA [18]	7,9,14,32,37	0.9378	**RGA [18]**	43,27,23,52,49,62,40,126,74,73,77,83, 31,110,33	0.9321	**GA [17]**	12,44,65,70,72	0.9428
HAS [12]	7,10,14,28,36	0.9336	**ITS[6]**	43,27,24,52,120,59,40,75,72,98,130, 131,110,35	0.9323	**SA [23]**	12,44,65,70,72	0.9428
BPSO	4,10,12,24,30	0.95379	**BPSO**	12,21,33,42,44,52,59,72,78,90,96	0.9335	**BPSO**	14,58,61,69,70	0.9495

TABLE IX. COMPARATIVE RESULTS FOR NR FOR CASE 3

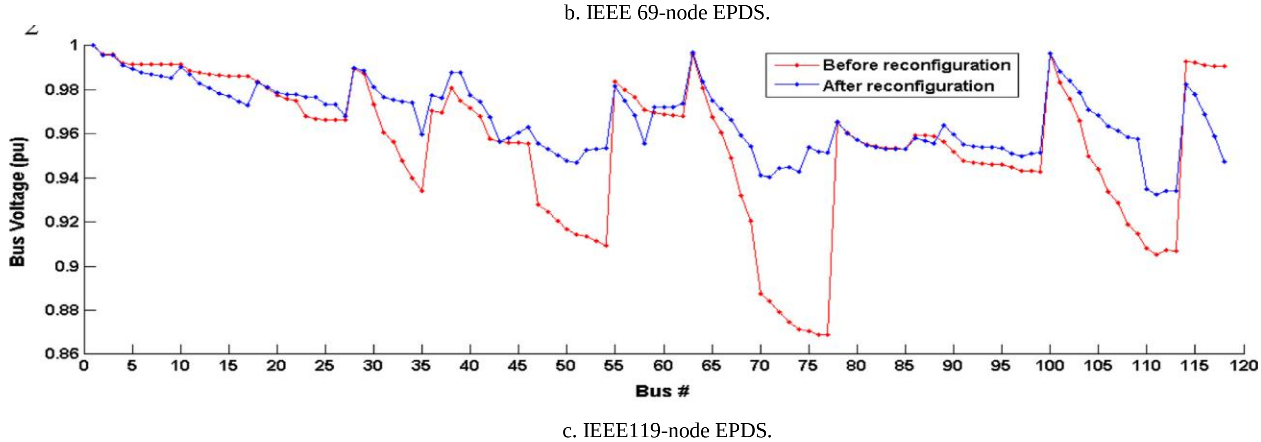
IEEE 33-node EPDS				*IEEE 69-node EPDS*				*IEEE 119-node EPDS*			
Method	***Tie switches***	***V_{min} (p.u)***	***Red_{Loss}***	***Method***	***Tie switches***	***V_{min} (p.u)***	***Red_{Loss}***	***Method***	***Tie switches***	***V_{min} (p.u)***	***Red_{Loss}***
initial	33,34,35,36,37	0.94234	-	**initial**	69,70,71,72,73	0.943	-	**initial**	119,120,121,122,123, 124 125,126,127,128, 129, 130, 131,132, 133	0.8667	-
FWA[23]	7,9,14,28,32	0.9413	30.93%	**FWA[23]**	14,56,61,69,70	0.9413	56.17%	**RGA[18]**	43,27,23,52,49,62, 40,126 74,73,77,83, 131,110,33	0.9321	31.9%
GA[17]	9,28,33,34,36	0.931	30.15%	**GA[17]**	13,18,56,61,69	0.9428	55.8%	**ITS [6]**	33,34,27,24,52,120, 59,40,96 75,72,98,130, 131,110	0.9323	33.3%
BPSO	7,9,14,32,37	0.94234	33.33%	**BPSO**	14,55,61,69,70	0.943	56%	**BPSO**	24,26,35,40,43,51, 59,72,75 96,98,110,122,130,131	0.93	34%



a. IEEE 33-node EPDS.



b. IEEE 69-node EPDS.



c. IEEE119-node EPDS.

Fig. 3. Voltage profile with and without NR implementation using the proposed procedure for different distribution systems

V. CONCLUSIONS

In this paper, a proposed reconfiguration procedure has been presented using the BPSO algorithm for losses reduction and voltage profile improvement. IEEE 33-bus, 69-bus and 119-bus distribution systems have been used for proving the effectiveness of BPSO algorithm to deal with small and large scale distribution systems. A multi-objective function has been used to achieve the simultaneous minimization of the power losses and improvement of the voltage profile for the tested systems. The reduces the losses for systems which saving of 83.75 kW, 126 kW and 621.21 kW for IEEE 33-bus, 69-bus and 119-bus distribution system. Also, the propose procedure improves the voltage profile for the tested networks. Comparative studies have been introduced to show the capability and efficiently of the proposed procedure compared with other methods.

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