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RECONFIGURATION AND DG PLACEMENT/SIZING IN RADIAL DISTRIBUTION SYSTEMS WITH A NEW INDEPENDENT LOOP IDENTIFICATION METHOD

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Abstract- This paper presents an algorithm for reconfiguration associated with placement and sizing of Distributed Generation (DG) to minimize energy losses and improve network voltage profile on radial electrical networks considering proposed algorithm to independent loop identification. An expression of analytical method to calculate the optimal DG size and location and Genetic algorithm for reconfiguration are used in this study. The proposed methodology was validated and examined in IEEE 33-bus distribution power system.

Keywords: Independent Loop, Distribution Generation Reconfiguration, Allocation, Sizing, Analytical Method.

I. INTRODUCTION

For reducing the short circuit current and facilitate their protection scheme, Distribution systems have been radially operated. Hence, a path from the system components to the substation is fed each load. So the systems include low voltage as well as low reliability with high power loss.

In the process of feeder reconfiguration, distribution network structures are changed by changing the status of switchgears. There are two kind of switching devices including sectionalizing as normally closed switches and tie as normally open switches. Since by changing the status of switches, the power flow to loads will be changed as result it affects the loss of power, voltages and reliability in normal operation status can improve the performance of distribution network as well as decrease the cost by correct switches status [1-5].

Electrical power demand is gradually increasing. Minimization of power loss for satisfying the power demand is very important issue. The role of distributed generation (DG) is vital in electrical power supplying and losses decreasing. The DGs are as embedded generation or decentralized generation generate power in the range of 3-10,000 kW. Stability, reduction of power loss, reliability and improving voltage are the main advantages of using DG units. When the DG units are designed properly, the reverse flow from larger DG units can lead to further damage to system, causing voltage fluctuations and cost increases. Hence, it is important to find the best designing for DG units to obtain losses minimization [6-9].

Reconfiguration and DG placement methods in radial networks are attractive alternatives for power flow control, voltage profile management, improving system stability, and losses minimization [10-16]. Reconfiguration methods are well discussed in [1-5] whereas DG allocation is addressed in [6-9]. Refs. [10-16] study the allocation and reconfiguration solutions of DG units.

The network reconfiguration was presented by Merlin and Back [1], in order to reduce the power loss by a heuristic technique called as branch-and-bound type. In 1990, the switch exchange method was recommended by Carlos, Castro and Ander [2]. The algorithm was tested in 17-node, three feeder network and established switching operations to reduce power losses. Naveen, Sathish Kumar and Rajalakshmi [3] suggested a heuristic algorithm to discover the tie switch position in each loop to decline loss.

In this paper, the network reconfiguration problem as the non-linear optimization issue is applied to modify bacterial foraging algorithm in a general context. For achieving optimal configuration, meta-heuristic algorithms, such as GA have gradually been utilized, because the heuristic methods are usually fast but they may not attain it and also meta-heuristic algorithms are utilized to minimize the loss [4].

In this paper, for considering the reconfiguration problem like determining the switch operation schemes, the enhanced genetic optimization algorithm is used. Therefore, improving the algorithm on crossover and mutation operations of original Genetic Algorithms are depend on the information of a single loop caused by closing a normally open switch. Refs [5-9] present the optimal DG allocation and size in radial power networks as well as power loss reduction and improving voltage profile with heuristic algorithms. But the results of heuristic methods are not reliable, then using analytical methods for DG placement will be useful.

In [16-22] an analytical expression to calculating optimum size and location for DG (Distributed Generation)/capacitor is proposed and the objective of DG/capacitor location is to decrease the losses. The suggested method is proper for the DG designing in power distribution systems. Until 2001, most previous studies cause in redundant losses and cannot output the minimum loss configuration because they have studied in a separate manner such as DG compensation problems without accounting bus reconfiguration, or applied reconfiguration problems without considering the capacitor/DG addition.

In [16], to determine the DG settings and feeder reconfiguration for optimizing the optimal loss in distribution networks, the simulated annealing method is used. The algorithm represents the DG placement after the reconfiguration, to decrease losses and improving voltage profile, is proposed in [15] too, considering different load levels. Ref. [16] employs DG placement and the network reconfiguration simultaneously too, to improve the system reliability and minimize energy losses and exposed to fulfil the constraints of operation and power quality.

In this paper, the network DG placement/sizing and reconfiguration increase the system efficiency in a multi-objective optimization problem. Despite to previous papers, where Independent loops were not identified, identification of Independent loops is the main section of this paper, where describes is section II. Beside of introduction, the paper is prepared in 8 sections as follows:

'Independent loop identification in large distribution network' presents independent loops of a network with a novel algorithm and is tested on 33-bus test distribution network.

'Reconfiguration Algorithm' presents a modified version of graph theory for distribution feeder reconfiguration. In this section Genetic Algorithm is applied to reconfiguration of distribution network.

'DG Placement/Sizing Algorithm', proposes an efficient analytical approach for capacitor placement in radial distribution systems that determine the size of capacitor with a purpose of minimizes of power loss and improving the voltage profile and the optimal locations.

'Proposed Methodology' describes to find independent loops, reconfiguration and the optimum size and location of capacitor in the distribution system with a flow chart. 'Results' presents the results of proposed method in test distribution network.

II. INDEPENDENT LOOP IDENTIFICATION IN LARGE DISTRIBUTION NETWORK

In Reconfiguration the topology of the network is changed by toggling the statuses of sectionalizing or normally closed switches that are strategically installed in certain system position. It is hard task to find the best configuration for large systems, substantially systems with a large number of sectionalizing switches. identification of Independent loops in a large network is difficult.

In this section, an algorithm is proposed to identify Independent loops of a network. The proposed methodology is analyzed on 33-bus test distribution network which is shown as single line diagram in Figure 1, includes 33 buses and 37 branches and total load of 3.72 MW and 2.3 MVAR. Ref. [16] gives data of network.

The computational procedure to find the independent loops in a distribution network is described as follow:

1. Find nodes from "to node" column in Table 1, where repeated two times. (These nodes in IEEE 33-bus test distribution network data are 29, 18, 15, 12 and 8)

2. Find paths of each node in step 1, from nodes to first node. (As shown in Figure 2, these paths in IEEE 33-bus test distribution network are L1_29, L2_29, L1_15, L2_15, L1_15, L2_15, L1_12, 2_12, L1_8 and L2_8). Each node have two paths.

3. Delete common sections in two paths of each node of steps 1 and 2 to creation of Loops. (As shown in Figure 3, there are 5 loops in IEEE 33-Bus test distribution network, but they are not Independent loops).

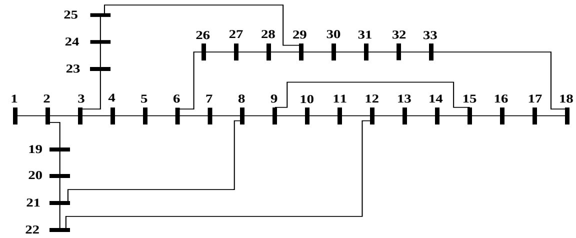


Figure 1. Single line diagram of IEEE 33-bus test distribution network

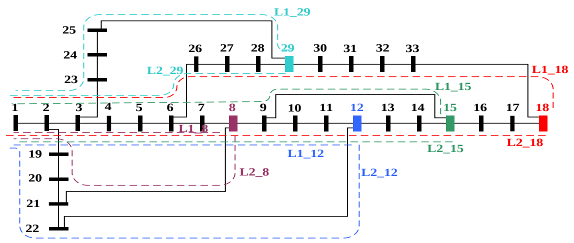


Figure 2. Directions of first node to loop nods in IEEE 33-bus test distribution network

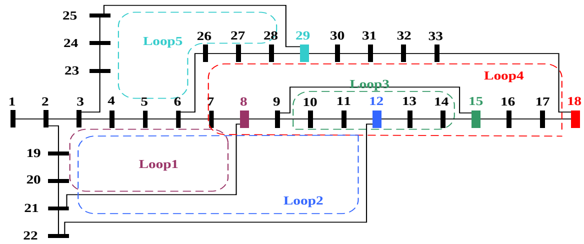


Figure 3. Loops nods in IEEE 33-bus test distribution network

4. Find Independent loops from loops of step 3 as follow:

4.1. Compare each loop of step 3 with each other. If *i*th loop has LNo_i sections and *j*th one has LNo_j sections and the common sections are LM, then number of distinct section in *i*th loop is $LD_i=LNo_i-LM$ and the distinct sections of *j*th one is $LD_j=LNo_j-LM$.

4.1.1. If $LNo_i>(LD_i+LD_j)$ or $LNo_j>(LD_i+LD_j)$ then:

- If $(LNo_j-(LD_i+LD_j))>(LNo_j>(LD_i+LD_j))$ then divide these loops to two Independent loops: *j*th loop and the new loop with distinct sections of *i*th and *j*th loops.
- If $(LNo_i-(LD_i+LD_j))<(LNo_j>(LD_i+LD_j))$ then divide these loops to two Independent loops: *i*th loop and the new loop with distinct sections of *i*th and *j*th loops.

4.2. If *i* is not loops of step 4.1 then, *i*th loop is independent loop.

Table 1 shows comparison of loops in Figure 3 to identify Independent loops. Figures 4(a) to 4(e) show the independent loops (Loop_M1, Loop_M2, Loop_M3 and Loop_M4), where achieved from step 4.1.

III. RECONFIGURATION ALGORITHM

Proper switching of tie and sectionalizing switches of the network, typically known as reconfiguration, may result in a significant loss reduction or voltage improvement in the network. The method which is employed in this paper for simultaneous feeder reconfiguration is the modified version of graph theory for distribution feeder reconfiguration. This method consist of below steps:

1. Opening one section of each independent loop to have a radial network.

2. Checking if the network is radial and all nodes are feeds from network or no. To check this step:

2.1. Dependence matrix (*MBusNo***SectionNo*) is developed as below, where *BusNo* is number of buses and *SectionNo* is number of sections:

$$M_{ij}=\begin{cases}1 & \text{if } i\text{th bus is connected to } j\text{th section}\\ 0 & \text{if } i\text{th bus is not connected to } j\text{th section}\end{cases}$$

2.2. Dependence matrix degree (*MDBusNo**1) is developed from *M* as: $MD_i=\sum_{j=1}^{SectionNo} M_{ij}$

2.3. Eliminate node with MD_i=1 and the connected section from network.

2.4. Repeat from 2.1 for 2**BusNo* times.

2.5. If *MD* matrix size is one*one, the network with opened sections in step 1 is accepted else the selected opened sections is not accepted.

From Table 1 and Figures 4(a) to 4(e), independent loops of IEEE 33-bus test distribution network is shown in Figure 5.

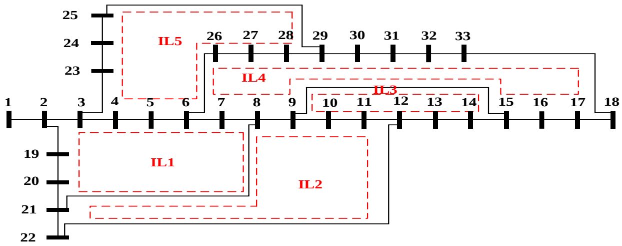


Figure 5. Independent loops of IEEE 33-bus test distribution network

Table 1. Independent loops of IEEE 33-bus test distribution network

*i*th loop of Figure 3	LNo_i	*j*th loop of Figure 3	LNo_j	*LM*	$LD_i=LNo_i-LM$	$LD_j=LNo_j-LM$	$LNo_i>(LD_i+LD_j)$	$LNo_j>(LD_i+LD_j)$	If $(LNo_i-(LD_i+LD_j))>(LNo_j>(LD_i+LD_j))$	If $(LNo_i-(LD_i+LD_j))<(LNo_j>(LD_i+LD_j))$	Independent Loops (Figures 4(a) to 4(e))
Loop 1	10	Loop 2	15	9	1	6	√	√	-	√	Loop_M1, Loop_M2 from step 4.1
		Loop 3	7	0	10	7	-	-			
		Loop 4	21	2	8	19	-	-			
		Loop 5	11	3	7	8	-	-			
Loop 2	15	Loop 1	10	9	6	1	√	√	√	-	Loop_M1, Loop_M2 from step 4.1
		Loop 3	7	3	12	4	-	-			
		Loop 4	21	6	9	15	-	-			
		Loop 5	11	3	12	8	-	-			
Loop 3	7	Loop 1	10	0	7	10	-	-			
		Loop 2	15	3	4	12	-	-			
		Loop 4	21	6	1	15	-	√	-	√	Loop_M3, Loop_M4 from step 4.1
		Loop 5	11	0	7	11	-	-			
Loop 4	21	Loop 1	10	2	19	8	-	-			
		Loop 2	15	6	15	9	-	-			
		Loop 3	7	6	15	1	√	-	√	-	Loop_M3, Loop_M4 from step 4.1
		Loop 5	11	4	17	7	-	-			
Loop 5	11	Loop 1	10	3	8	7	-	-			Loop 5 from step 4.2
		Loop 2	15	3	8	12	-	-			
		Loop 3	7	0	11	7	-	-			
		Loop 4	21	4	7	17	-	-			

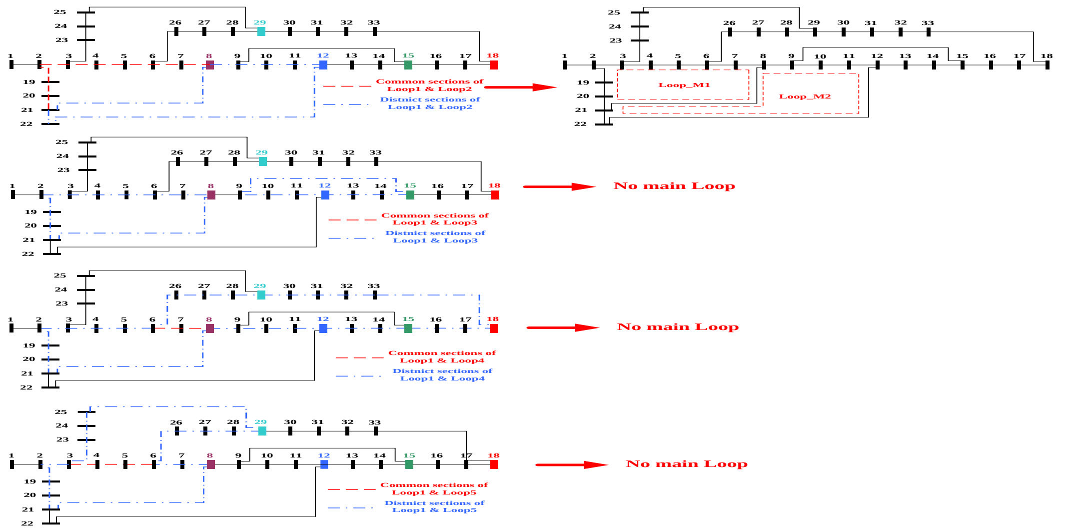


Figure 4(a). Common & distinct sections of Loop 1 and Loops 2, 3, 4, 5 in IEEE 33-bus test distribution network to identify main loops

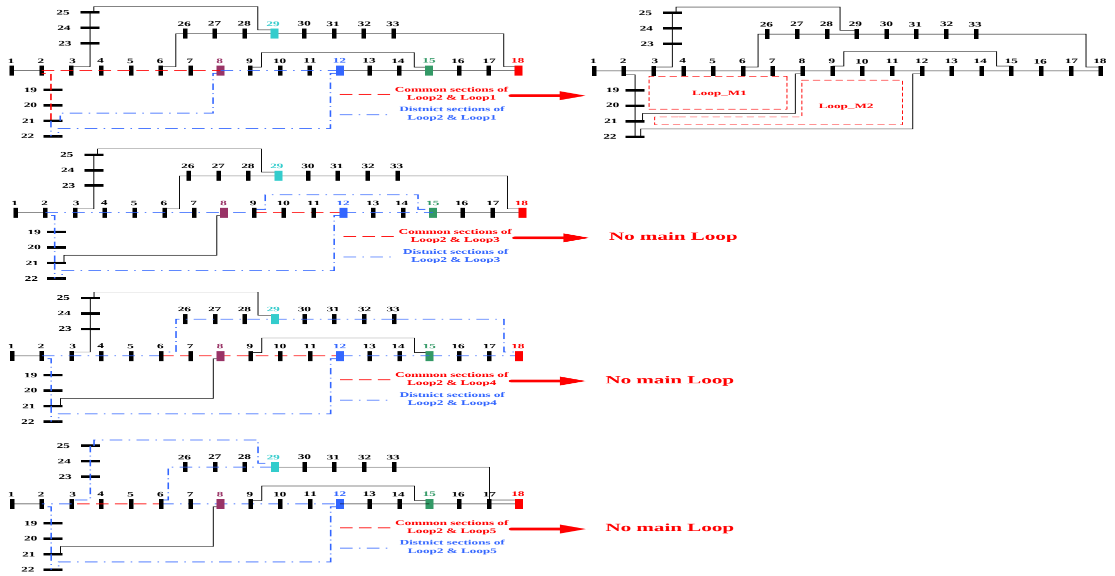


Figure 4(b). Common & distinct sections of Loop 2 and Loops 1, 3, 4, 5 in IEEE 33-bus test distribution network to identify main loops

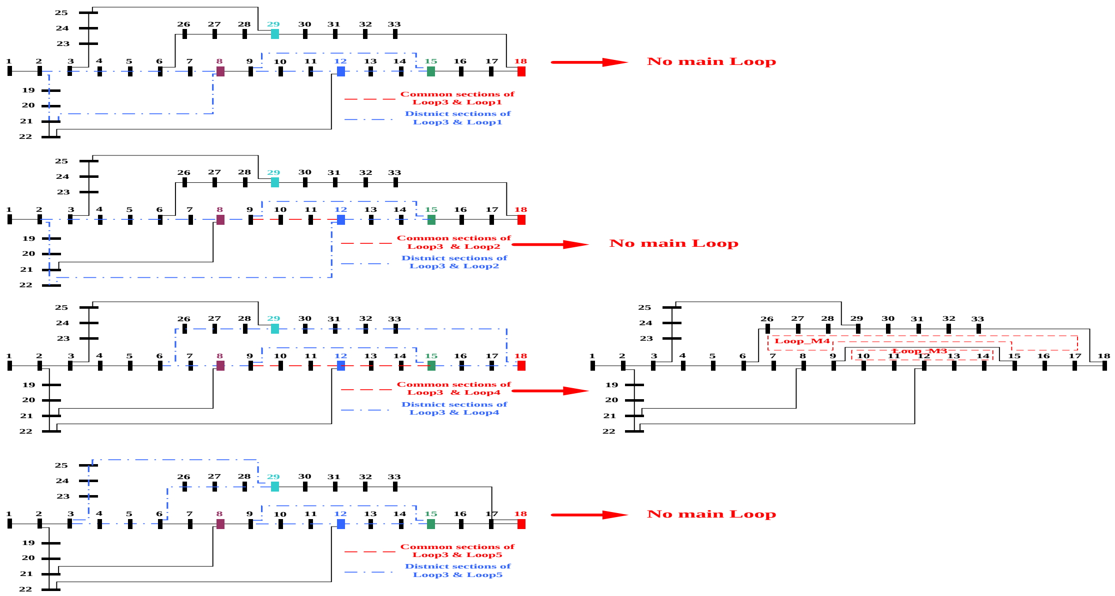


Figure 4(c). Common & distinct sections of Loop 3 and Loops 1, 2, 4, 5 in IEEE 33-bus test distribution network to identify main loops

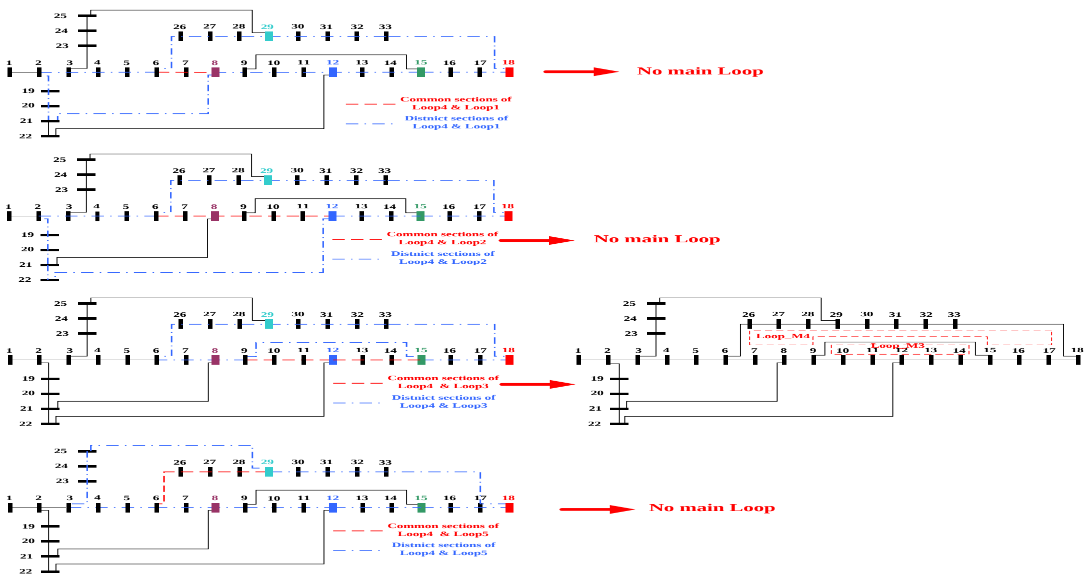


Figure 4(d). Common & distinct sections of Loop 4 and Loops 1, 2, 3, 5 in IEEE 33-bus test distribution network to identify main loops

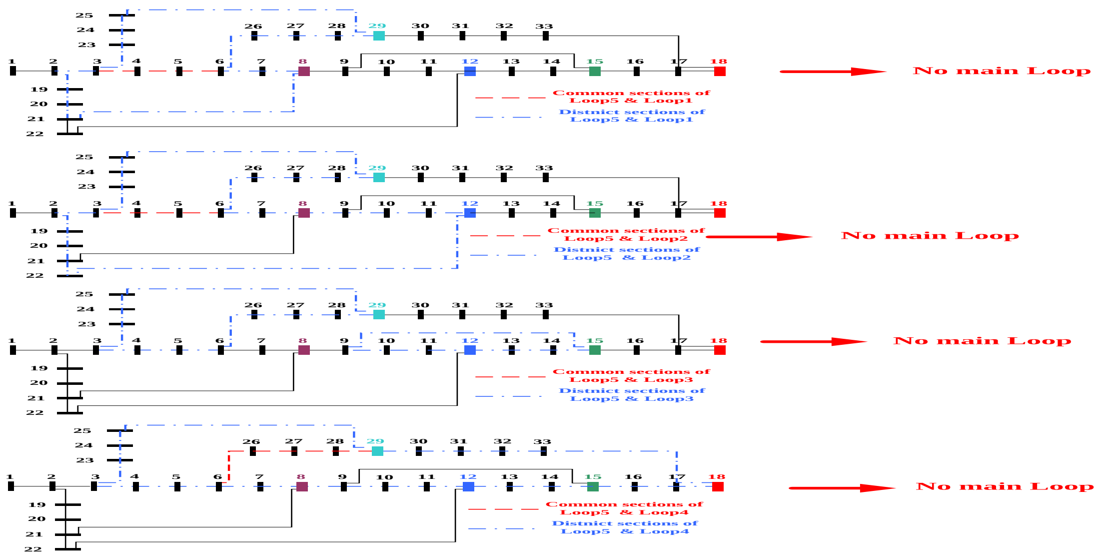


Figure 4(e). Common and distinct sections of Loop 5 and Loops 1, 2, 3, 4 in IEEE 33-Bus test distribution network to identify main loops

IV. DG PLACEMENT/SIZING ALGORITHM

The radial distribution networks using optimal DG placement is important for power flow control, voltage profile management, improving system stability, voltage profile management, and losses minimization. The proposed methods for DG placement issue can be arranged into four aspects including analytical, numerical programming, heuristic and artificial intelligence-based (AI-Based). This paper introduces an effective method for optimal placement and sizing of DG units in radial distribution networks to minimize of power loss and improve the voltage profile. Newton/Raphson load flow method is used for calculation of active and reactive power loss and node voltages in this paper. The optimal DG designing in size and location effects in minimum loss in the distribution system. Considering N bus distribution system, network may be formulated as given below active loss equation:

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j - P_iQ_j)] \quad (1)$$

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j)\ ;\ \beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_j) \quad (2)$$

where, $[Z_{bus}] = [Y_{bus}]-1$ is impedance matrix, $r_{ij} = \text{real}(Z_{ij})$, $x_{ij} = \text{imag}(Z_{ij})$, $V_i < \delta_i$ is ith bus voltage, P_i and Q_i are injected active and reactive power of ith bus.

To minimize network loss with DG installation, the rate of change of losses with respect to injected active power and power factor $(Q_{DGi} = a_iP_{DGi})$ are zero as Equation (3):

$$\frac{\partial P_L}{\partial P_i} = 2\alpha_{ii}P_i + 2\sum_{j=1, j\neq i}^{N}(\alpha_{ii}P_j - \beta_{ij}Q_j) = 0$$
$$\frac{\partial P_L}{\partial a_i} = 0 \quad (3)$$

where, $P_i = P_{Gi} - P_{Di}$ is injected reactive power, P_{Gi} is DG active power and P_{Di} is load active power in ith bus. Therefore, Equation (3) can be rewritten as bellows:

$$P_{Gi} = P_{Di} - \frac{1}{\alpha_{ii}} \sum_{\substack{j=1 \\ j \neq i}}^{N} (\alpha_{ii} P_j - \beta_{ij} Q_j)$$
$$a_i = \frac{\alpha_{ii} Q_{Di} - B_i}{\alpha_{ii} P_{Di} - A_i} \quad (4)$$

Equation (4) results the size of DG at each bus. If this DG located at ith bus the minimum real power loss is resulted compared to the same DG placed at any other bus.

Then ith bus is the optimal place for this DG unit. Any size of DG rather than P_{Gi} and located at bus i, will lead to higher losses. In this study, both of loss and voltage profile is important is placing DG and the placement algorithm is as follow:

1. Base load flow (backward/forward) and computing network loss ($P_{Loss,Base}$) with Equation (1) and voltage sensitivity with Equation (5).

$$V_{Sens,Base} = \sum_{j=1}^{BusNo} ((\| V_j \| - 1|) \times \frac{P_{Lj}}{\sum_{j=1}^{BusNo} P_{Li}}) \quad (5)$$

where, P_{Lj} is active load of jth bus.
2. Computing DG size for each bus with Equation (4).
3. Placing each DG of step 2 in its bus and computing network loss (P_{Loss}) with Equation (1) and voltage sensitivity (V_{sens}) with Equation (5).
4. Computing cost function for each bus as Equation (6).

$$F_{Cost} = W_1 \frac{P_{Loss,Sens}}{P_{Loss,Sens,Base}} + W_2 \frac{V_{Sens}}{V_{Sens,Base}}$$

where, W_1 and W_2 are weights and $W_1 + W_2 = 1$.
5. Sort Fcost function for buses and accept the bus with minimum cost as best bus to set capacitor with the size of step 2.

In this section, related to previous sections, the proposed methodology is described to find independent loops, reconfiguration and the optimum size and location of DG in the distribution system. Figure 6 illustrates the flowchart for the proposed methodology to reconfiguration and optimal placement of DGs in the distribution system through applying genetic and analytical methods. In this flowchart, the hatched block denotes DG allocation algorithms described in section IV. Also "Calculate loop number" block denotes algorithm in section II to find independent loops and the "graph theory" block refers to section III.

V. RESULTS

The results obtained with the proposed methodology are presented in the paper. The 33-bus system, 12.66 kV and 10 MW is used and the substation voltage is considered as 1.0 p.u. As presented in table 2, in this initial topology, the open branches are 33, 34, 34, 36 and 37 and the total active power loss and voltage sensitivity are 211 kW and 0.0517 respectively.

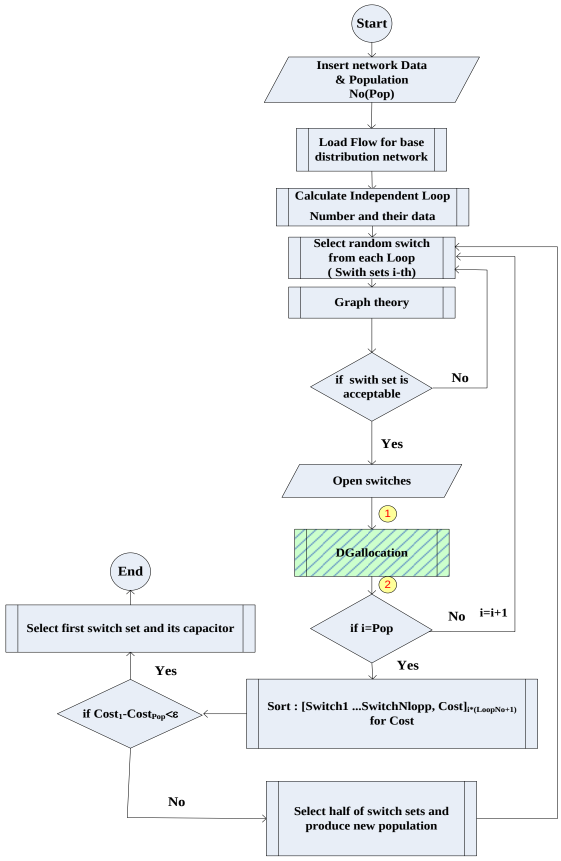


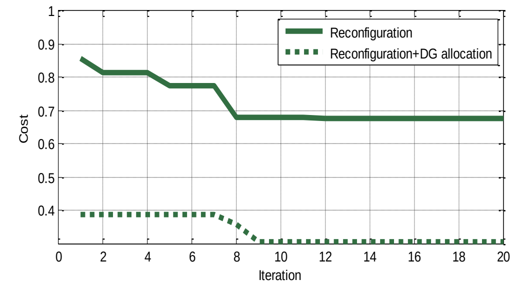
Figure 6. Flowchart of proposed methodology

Table 2. Main network results

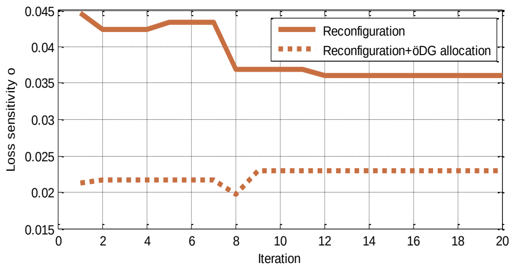
Main network		
Open Switches	Loss (kw)	Voltage Sensitivity
33-34-35-36-37	211	0.0517

In this paper, setting of switched DGs feeder and reconfiguration are taken into account together. We had attended mentioned cases of the applications. The mentioned four cases include as follows:
Case 1. Comparison of both feeder reconfigurations with one DG addition and feeder reconfiguration simultaneously, is considered.
Case 2. Comparison of both feeder reconfigurations with two DGs addition and feeder reconfiguration simultaneously, is considered.
Case 3. Comparison of both feeder reconfigurations with three DGs addition and feeder reconfiguration simultaneously, is considered.
Case 4. Comparison of both feeder reconfigurations with four DGs addition and feeder reconfiguration simultaneously, is considered.

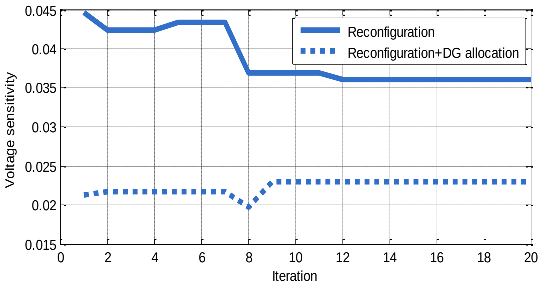
As shown in Table 3, for W_1=0.5, the cost of all cases for only reconfiguration or reconfiguration with DG allocation are equal approximately. Comparison of only reconfiguration and reconfiguration with DG allocation for each case, shows that DG allocation with reconfiguration cause near 20% reduction of cost. Figures 7 to 10 show simulation results of all four cases. Number of iteration for all cases is 20.



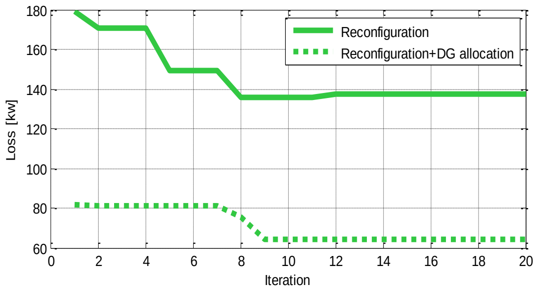
(a). Cost



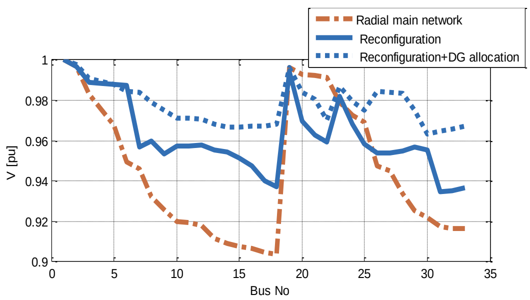
(b). Loss sensitivity



(c). Voltage sensitivity

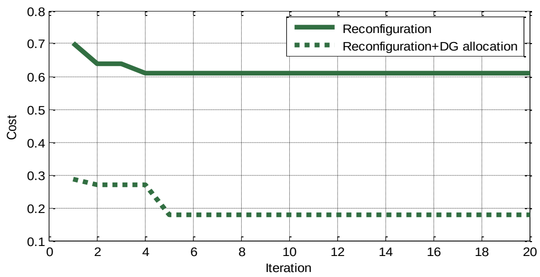


(d). Loss (KW)

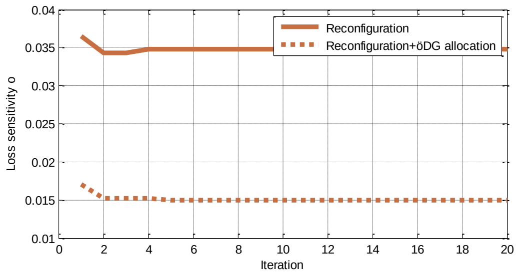


(e). Voltage

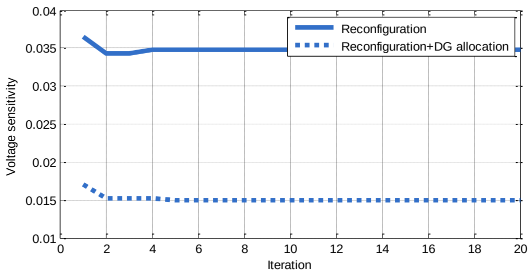
Figure 7. Reconfiguration and Reconfiguration with one DG allocation, Case 1



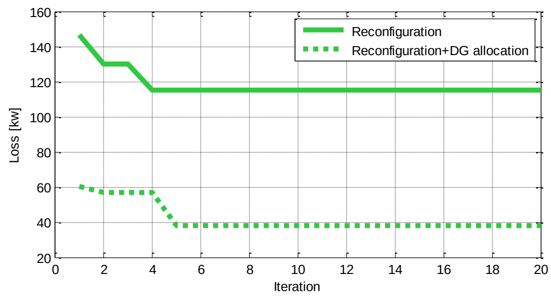
(a). Cost



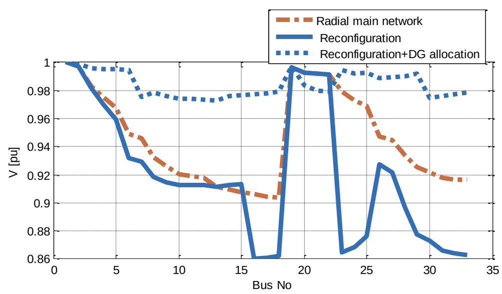
(b). Loss sensitivity



(c). Voltage sensitivity

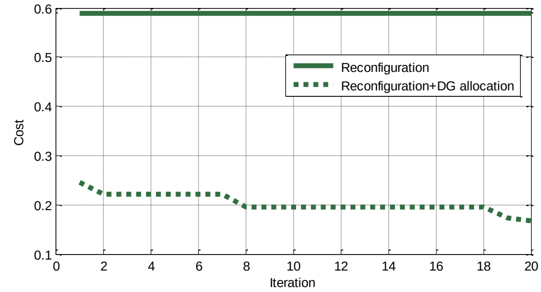


(d). Loss (KW)

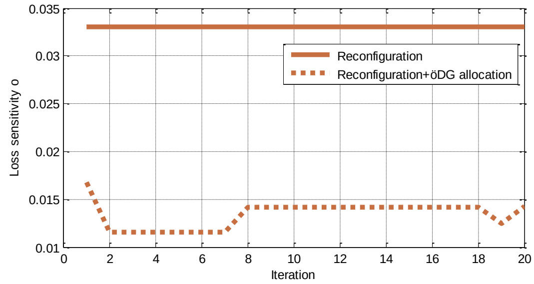


(e). Voltage

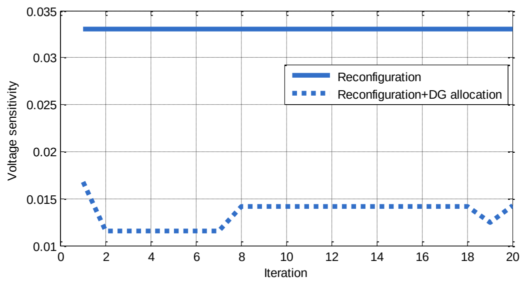
Figure 8. Reconfiguration and Reconfiguration with two DG allocation, Case 2



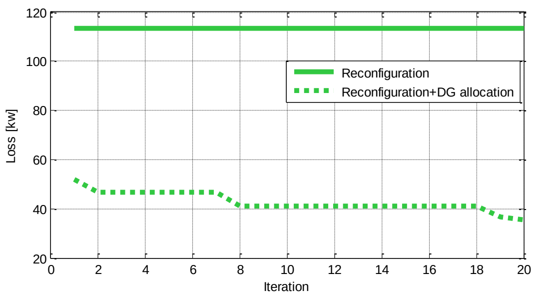
(a). Cost



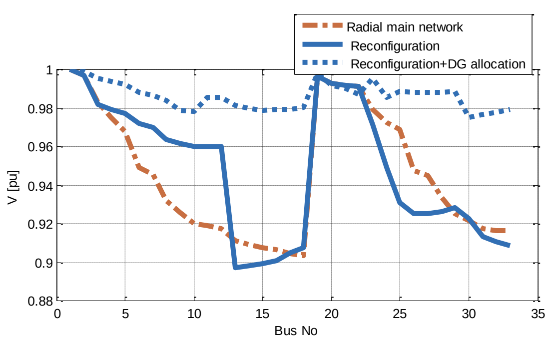
(b). Loss sensitivity



(c). Voltage sensitivity

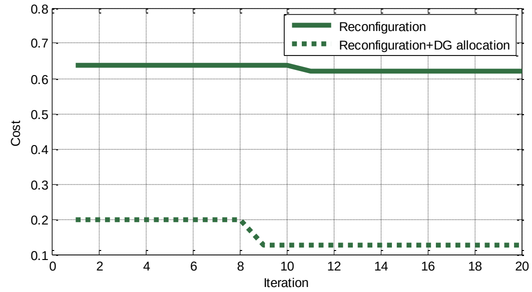


(d). Loss (KW)

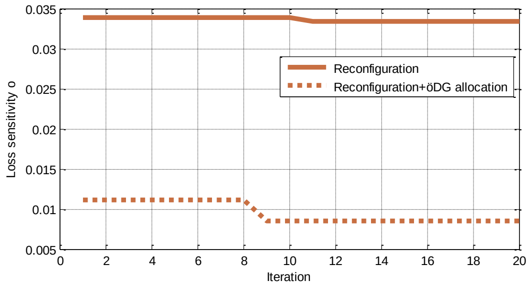


(e). Voltage

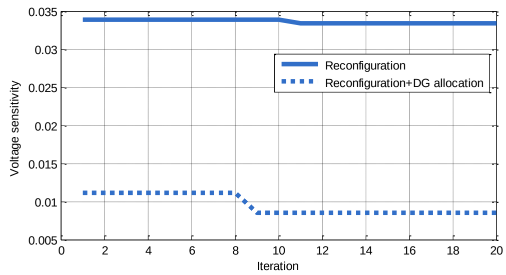
Figure 9. Reconfiguration and Reconfiguration with three DG allocation, Case 3



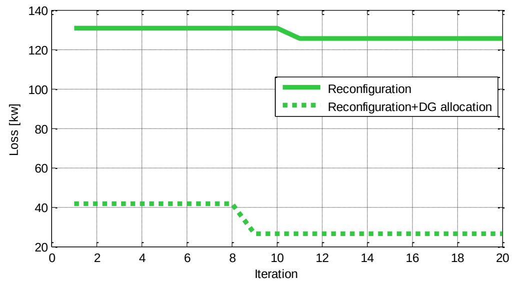
(a). Cost



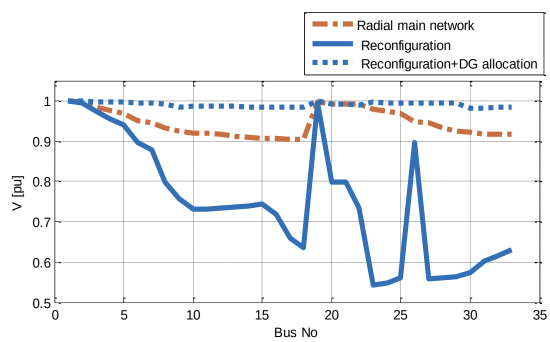
(b). Loss sensitivity



(c). Voltage sensitivity



(d). Loss (KW)



(e). Voltage

Figure 10. Reconfiguration and Reconfiguration with four DG allocation, Case 4

Table 3. Reconfiguration and DG allocation results

Case No	Reconfiguration					Reconfiguration and DG allocation																
	Open Switches	Loss (kw)	Loss sensitivity	Voltage sensitivity	Cost	Open Switches	Loss (kw)	Loss sensitivity	Voltage sensitivity	Cost	1st DG location	1st DG size	1st DG size (KW)	2nd DG location	2nd DG size	2nd DG size (KW)	3rd DG location	3rd DG size	3rd DG size (KW)	4th DG location	4th DG size	4th DG size (KW)
1	6-37-14-34-33	137	0.65	0.036	0.67	7-21-35-29-28	64	0.3	0.022	0.3	18	504	1104	-	-	-	-	-	-	-	-	-
2	7-36-13-29-28	114	0.54	0.034	0.6	6-36-13-29-25	37	0.17	0.014	0.17	18	521	1192	25	602	1192	-	-	-	-	-	-
3	7-37-14-31-24	113	0.53	0.033	0.58	37-8-10-29-23	35	0.167	0.0143	0.167	18	477	1085	22	692	397	25	529	1051	-	-	-
4	37-10-35-31-28	125	0.59	0.033	0.62	37-8-13-29-27	26	0.125	0.0085	0.125	4	7	499	695	22	644	25	602	1171	33	442	1026

VI. CONCLUSION

Feeder reconfiguration and DG placement approach employing new method of independent loop identification is used to minimize energy losses and improving network voltage on radial electrical networks. Several major observations can be derived from the studies, as follows:

New algorithm to independent loop identification is used for large networks.

1. GA is used for reconfiguration.
2. Analytical method is applied for DG allocation.
3. proper feeder reconfiguration and capacitor inserting will effectively reduce power losses of distribution networks.
4. Considering both setting of DG and feeder reconfiguration can effect on losses reduction than considering them lonely or separately (approximately 20%).
5. Moreover, the voltage profile can be improved as well as the power-loss reduction by the proposed method.
6. With a proper weights, loss reduction and voltage improvement is achieved in this study.

The proposed approach was tested and validated in IEEE 33-bus distribution test system.

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