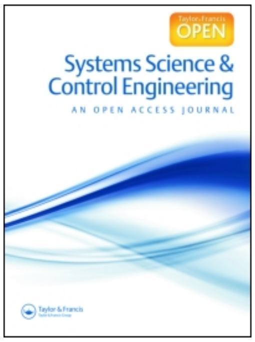

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Two-level reconfiguration algorithm of branch exchange and variable neighbourhood search for active distribution network

Qingxiang Hao, Zhengzhong Gao, Xingzhen Bai and Maoyong Cao

College of Electrical Engineering and Automation, Shandong University of Science and Technology, Qingdao, People's Republic of China

ABSTRACT

In this paper, a two-level algorithm is proposed to solve the distribution network reconfiguration with an objective of minimum power loss. In the first level reconfiguration, switches of maximum power loss reduction are disconnected by the branch exchange (BE) algorithm. Based on the results, neighbourhoods of disconnected switches are constructed by the deterministic transform method in the second level. The variable neighbourhood search (VNS) algorithm keeps searching the neighbourhoods to obtain a better solution with a lower power loss. Simulations are carried out on IEEE33 and PG&69 distribution networks to verify the superiority of the proposed algorithm. The obtained results are compared with the other methods available in the paper. It can be concluded that the presented method has both high stability and rapidity.

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Distribution system reconfiguration; nonlinear combinatorial optimization; branch exchange algorithm; variable neighbourhood search algorithm; distributed generation

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1. Introduction

Reconfiguration entails altering the topology of the distribution network by changing the open/close states of switches under operating conditions. It can reduce power loss and improve the voltage profile as well as system reliability. Since there are many possible combinations of sectionalizing and tie switches in a system, finding a radial network with the lowest power loss becomes a NP-hard problem.

The distribution network reconfiguration for loss reduction was first solved by Merlin and Back using a branch and bound-type algorithm (Merlin & Back, 1975, September). In the following 40 years, many researchers had solved this problem with various methods, such as heuristic algorithms (Bi, Liu, & Zhang, 2001; Civanlar, Grainger, Yin, & Lee, 1988), artificial intelligence algorithms (Francisco, Susel, Ines, Miguel, & Emilio, 2016; Inji, Hamdy, Nagi, & Danielle, 2017, June; Jalal & Ahmad, 2015; Mohamed Imran & Kowsalya, 2014; Mohammad, 2017, June; Naji, Cindy, & Li, 2016; Rayapudi, Sadhu, Manyala, & Srinivasa Rao, 2011; Tahboub, Ravikumar Pandi, & Zeineldin, 2015; Wang & Chen, 2008) and mathematical optimization methods (Joshua & Franz, 2012; Lin et al., 2013; Lin et al., 2014; Rabih, Ravindra, & Bikash, 2012). The heuristic algorithms achieve the goal of reducing active power loss by redistributing the load in the network. The BE algorithm for reconfiguration was presented by Civanlar et al. (1988), where a formula was proposed to calculate the power loss caused by switch exchange. Based on Civanlar et al. (1988), Bi et al. (2001) improved and simplified the formula. It would greatly reduce the computation time if only the distance from the ideal transferred load to the load transferred is obtained. The disadvantages of the above heuristic algorithms are: (1) only one pair of branches is considered at a time and (2) the optimal structure relies on the initial switch states. Later on, numerous artificial intelligence algorithms such as genetic algorithm (GA) (Jalal & Ahmad, 2015; Tahboub et al., 2015), particle swarm optimization (PSO) (Inji et al., 2017, June; Mohammad, 2017, June; Naji et al., 2016), harmony search algorithm (HSA) (Rayapudi et al., 2011), fireworks algorithm (FWA) (Mohamed Imran & Kowsalya, 2014), plant growth simulation algorithm (Wang & Chen, 2008) and open shortest path first routeing protocol (Francisco et al., 2016) had been proposed to solve the reconfiguration problem with various objectives under operating conditions. Although the solution of minimal power loss can be obtained, these methods are very time-consuming. In addition to the above algorithms, mathematical optimization methods were also used to solve the reconfiguration problem in the distribution system, such as graph theory and mixed-integer linear programming.

CONTACT Zhengzhong Gao skdhqx@163.com

Lin et al., (2013, 2014) combined theory graph and the artificial intelligence algorithm to ensure that every newly generated network is radial. Joshua & Franz (2012) and Rabih et al. (2012) regarded the network model as a convex representation which is based on the conic quadratic format of the power flow equations. These algorithms converge well and can obtain the best solution. However, for larger systems, the computation time is too long to be suitable for real-time operations. In summary, the above traditional reconfiguration algorithms cannot easily balance the computing speed and the quality of solutions.

With the continuous development of the economy and society, a growing number of distributed generations (DG) have been connected to the smart distribution network (Wang et al., 2017). Bai, Yiango, Dani, & Chris (2016), Nikolaos, Dimitris, Pavlos, and Nikos, (2017) and Xing and Sun, (2017) had proved that DG can reduce cost and improve the delivered power quality as well as system reliability. However, the renewable DG units cannot guarantee a fixed power output due to the uncertainties such as load demand, wind speed, and solar radiation. In addition, the integration of plug-in electric vehicles will bring problems of feeder overloading and loss increase as reported in Abdollah, Mohammad, and Taher (2015), Mohammad, Abdollah, and Taher (2015) and Zhang, Zhang, Xu, Zhou, and Zhang (2017, October). Arash, Thomas, and Saeed (2016) and Hajar, Mohd, and Rizwan (2015) had employed reconfiguration as a reliability-enhancing strategy to significantly reduce the adverse effects of DG interconnection.

In this paper, in order to improve the searching speed and the quality of the solution of the reconfiguration algorithm, a two-level algorithm based on BE and VNS is proposed for the minimization of power loss in the active distribution network. The main contributions are as follows:

(1) A new heuristic rule of the BE algorithm is obtained by improving the estimation formula of active power loss. The maximum power loss reduction is generated by breaking the switch whose current is close to the ideal transferred current. It would greatly reduce the computation time and obtain a solution with lower power loss.

(2) A new neighbourhood construction method is proposed in the VNS algorithm. The neighbourhood of the disconnected branch consists of its clockwise and counter clockwise branches in loop. VNS obtains the results of lower power loss by searching the changing neighbourhood to find the global optimal solution. To avoid unexpected interrupts in constructing neighbourhood before finding the optimal solution, the neighbourhood branch should be corrected to skip the bus without any load according to the search direction. It can decrease the search space and prevent the proposed algorithm from falling into the local optimal solution effectively.

This paper is organized as follows. Section 2 gives the mathematical model. Section 3 provides the application of the two-level algorithm for power loss minimization. Section 4 presents simulations and analysis of IEEE33 and PG&69 distribution networks. Finally, Section 5 outlines the conclusions.

2. Mathematical model

The essence of the distribution network reconfiguration is to find a radial network with minimum active power loss while the imposed operating constraints are satisfied. The objective function for the minimization of active power loss is described as

$$\min P_{\text{loss}} = \sum_{i=1}^{n} r_i |I_i|^2 \tag{1}$$

where P_{loss} is the total active power loss of the system; n is the amount of branches of the system; r_i is the resistance of branch i and I_i is the current of branch i. The operating constraints are listed as

$$\begin{cases} U_{\min} \le U_j \le U_{\max} \\ S_i \le S_{i\max} \\ g_k \in G \end{cases} \quad \begin{cases} P_{\text{D},h} \le P_{\text{D},h}^{\max} \\ Q_{\text{D},h} \le Q_{\text{D},h}^{\max} \end{cases} \tag{2}$$

where U_j is the voltage magnitude of bus j; $U_{\min}, U_{\max}$ are the minimum and maximum voltage limits of bus; S_i, $S_{i\max}$ are the apparent power and maximum limit of branch i; g_k is the newly generated network; G is the radial network; $P_{\text{D},h}$, $P_{\text{D},h}^{\max}$ are the active power and maximum limit of h DG; and $Q_{\text{D},h}$, $Q_{\text{D},h}^{\max}$ are the reactive power and maximum limit of h DG.

3. Application of the two-level algorithm for power loss minimization

3.1. The first level reconfiguration based on the BE algorithm

BE was proposed by Civanlar et al. (1988). The characteristic of BE is to close a tie switch to form a loop and then open a sectionalizing switch in this loop to get back to radiation. The amount of active power loss change due to

BE can be estimated from the following formula:

$$\Delta P_{\text{loss}} = 2 \times \text{Re}\left[\left(\sum_{i \in D} I_i\right)(V_a - V_b)^*\right] + R_{\text{loop}} \times \left|\sum_{i \in D} I_i\right|^2 \tag{3}$$

where ΔP_{loss} is the amount of active power loss change; D is the buses with load transferred; I_i is the complex current of branch i; V_a, V_b are the voltage drop from source to bus a and b; and R_{loop} is the total resistance of all the branches in loop.

In general, the reactive power of the distribution network is sufficient, and the voltage phase-angle difference between buses is so small which can be negligible. Therefore, Equation (3) can be simplified as

$$\Delta P_{\text{loss}} = 2 \times \left(\sum_{i \in D} I_i\right)(V_a - V_b) + R_{\text{loop}} \times \left|\sum_{i \in D} I_i\right|^2 \tag{4}$$

where I_i is the current amplitude of branch i and V_a, V_b are the voltage loss amplitude from source to bus a and b.

Since the second part is always positive in Equation (4), ΔP_{loss} is possible to be negative when $|V_a| < |V_b|$. Therefore, the heuristic rule can be obtained as it is possible to reduce the active power loss only when the loads are transferred to the bus with a smaller voltage loss.

Replacing $\sum_{i \in D} I_i$ with I_x, then Equation (4) becomes:

$$\Delta P_{\text{loss}} = 2I_x(V_a - V_b) + R_{\text{loop}} I_x^2 \tag{5}$$

Taking I_x as an independent variable and ΔP_{loss} as a dependent variable, then Equation (5) can be regarded as a quadratic. Its minimum is

$$\begin{cases} I_{\text{opt}} = \dfrac{V_a - V_b}{R_{\text{loop}}} \\ \Delta P_{\text{loss,max}} = \dfrac{-(V_a - V_b)^2}{R_{\text{loop}}} \end{cases} \tag{6}$$

where I_{opt} is the ideal transferred current and $\Delta P_{\text{loss,max}}$ is the maximum reduction of active power loss.

From the above, we can get a new heuristic rule. The maximum power loss reduction is generated by breaking the sectionalizing switch whose current is closet to I_{opt}. The new rule greatly decreases the number of candidate switches and computational complexity. Therefore, it helps to cut down the computation time.

3.1.1. The steps of BE for power loss minimization

The coding strategy of the integer loop is used to encode all branches in loops. In addition, several branches that are not in any loop should not be coded and must be closed when the distribution network is reconstructed. For example, there are five loops in the IEEE33 distribution network of Figure 1. The branches in loop 1 are coded as $[S_7, S_6, S_5, S_4, S_3, S_2, S_{20}, S_{19}, S_{18}, S_{33}]$ and branch S_1 should not be coded into any loop that has been always closed.

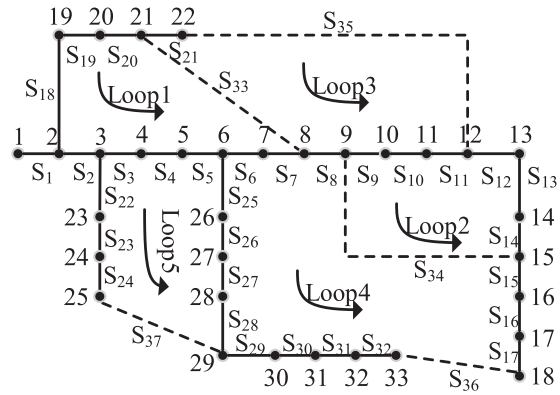

Figure 1. IEEE33 distribution network.

The first level reconfiguration of the distribution network based on BE is shown in Figure 2. Its main steps are as follows:

Step 1. Input the data of branches and buses of the system, initialize parameters, and then make $l = 1$.

Step 2. Calculate the power flow, and then get the current amplitude of each branch in loop l. Get V_a and V_b, that is, the voltage loss amplitude at ends of a tie switch in loop l.

Step 3. Close the tie switch to form a loop, and then get I_{opt} and R_{loop} of loop l.

Step 4. The branches in loop l, connected to larger one in V_a and V_b, are stored in candidate branch set (*CBS*). And these branches are sorted by the difference between its current and I_{opt}.

Step 5. Disconnect the first branch in *CBS*, and make the network return to radiation.

Step 6. Do the newly generated networks satisfy the operating constraints? If yes, accept the newly generated networks and go to step 7. If not, remove this branch from the *CBS* and return to step 5.

Step 7. Is l greater than 5? If yes, output active power loss p and the corresponding disconnected branch set s. If not, go to the next loop and return to step 2.

The improved BE algorithm can greatly reduce the number of switching combinations and computation time. And it clearly indicates the direction of the power loss reduction. However, it can only deal with a pair of switching operations at a time, so the solution is not often the optimal.

3.2. The second level reconfiguration based on the VNS algorithm

Since the solution is not optimal in the first level reconfiguration, VNS will continue to optimize it in the second level. In Yannis, Athanasios, and Angelo, (2017), the neighbourhoods have been reconstructed continuously based on the current local optimal solution to find a better one until the global optimal solution is found.

3.2.1. Construct neighbourhood based on the deterministic transform method

The neighbourhood of the disconnected branch consists of its clockwise and counter clockwise branches in the loop. Taking the PG&69 distribution network of Figure 3 as an example, the disconnected branch is S_{14} in loop 3 and S_{13}, S_{71} are the clockwise and counter clockwise neighbourhood branches. However, disconnecting the branch on either side of the bus without any load, the power loss is the same. To avoid unexpected interrupts in constructing neighbourhood before finding the optimal solution, the neighbourhood branch should be corrected to skip the bus without any load according to the search direction. That is, no load on bus 15 of the PG&69 distribution network in Figure 3, the counter clockwise neighbourhood S_{14} should be corrected to S_{45}, while the clockwise neighbourhood stays unchanged, still being S_{13}.

3.2.2. The steps of VNS for power loss minimization

The coding strategy is the same as in the first level reconfiguration. Several branches that are not in any loop should not be coded and must be closed, such as S_1, S_{27} and so on. The switch status in other loops should remain unchanged when constructing the neighbourhood of a branch in a loop. Firstly, the disconnected branch should be closed, and then we open its clockwise and counter clockwise neighbourhood branches to form two new networks. After all the neighbourhoods of disconnected switches have been constructed, the newly generated radial networks are stored in a set. The network with minimum power loss in this set is selected as the initial solution for the next iteration. If the minimum power loss is the same as the last iteration, VNS stops and outputs the solution. Otherwise, VNS iteratively seeks the optimal solution. The second level reconfiguration based on VNS is shown in Figure 4. And its main steps are as follows:

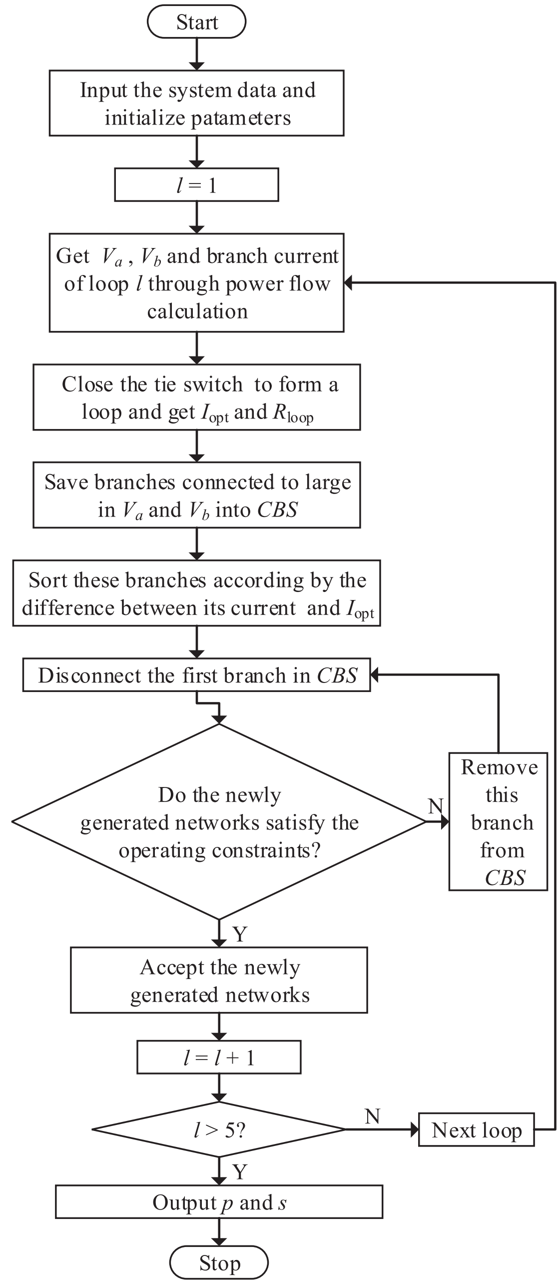

Figure 2. Flow chart of the first level reconfiguration based on BE.

Step 1. Input p and s of the first level reconfiguration as the initial solution.

Step 2. Close the disconnected branch, and then open its clockwise and counter clockwise neighbourhood branches in the loop. Consequently, two new networks have been generated.

Step 3. Is there load between the closed and disconnected switches? If yes, go to step 4. If not, disconnect the next branch according to the search direction, and then go to step 4.

Step 4. Do the newly generated networks satisfy the operating constraints? If yes, add these networks into *SS*, and then go to step 5. Else, discard these new networks, and then go to step 5.

Step 5. Have all the loops been searched? If yes, go to step 6. Otherwise, go to the next loop and return to step 2.

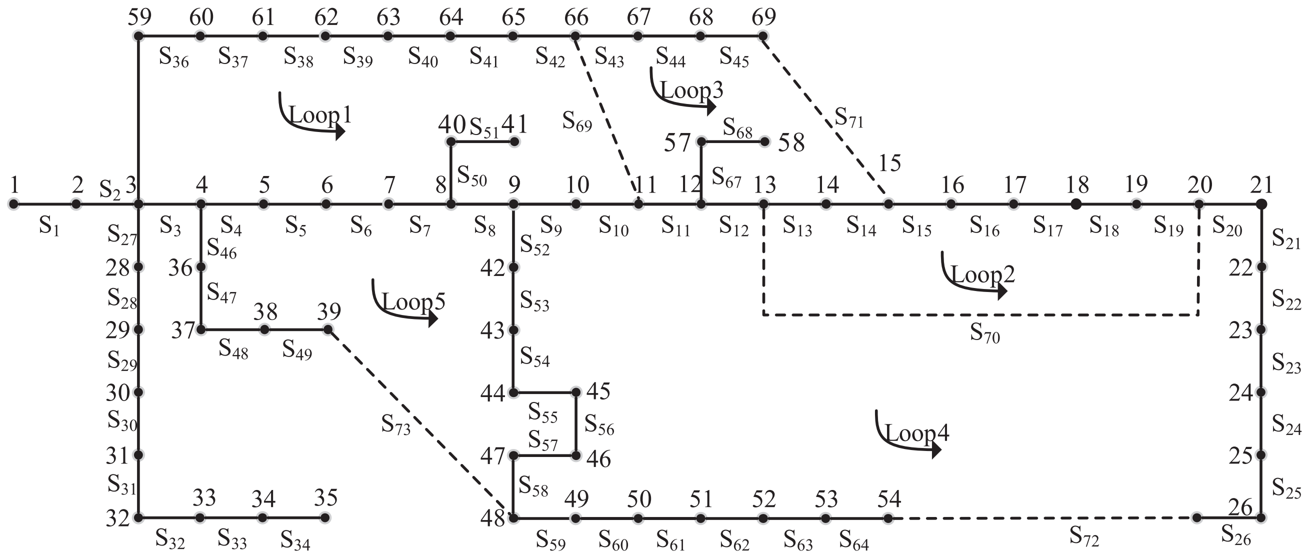

Figure 3. PG&69 distribution network.

Step 6. Select the network with minimum power loss (p_{min}) in set *SS*. If the p_{min} is the same as the result of the last iteration, end and output the p_{min} and s_{min}. Else, return to step 2.

4. Simulations and analysis

The proposed method is tested on the radial distribution networks of IEEE33 and PG&69, and the corresponding results are obtained to evaluate its stability and rapidity. For all networks, the substation voltage is considered as 1.0 p.u., and all the sectionalizing and tie switches are considered as candidate switches for solving reconfiguration problems. It adopts the back/forward substitution method for radial distribution load flow based on node-layer (Li, Xie, Wang, & Chu, 2010). The proposed algorithm was developed in MATLAB R2014a, and the simulations were done on a computer with Inter i5-2410M, 2.30 GHz, 4GB RAM.

4.1. Case 1

The first example system is the IEEE33, 12.66 kV, 33 buses radial distribution network as shown in Figure 1. The normally closed sectionalizing switches are S_1–S_{32}, and the normally open tie switches are S_{33}–S_{37}. There are five loops in this system (loop 1 to loop 5) formed corresponding to each tie switch. The total active and reactive power loads are 3715 kW and 2300 kvar.

The proposed algorithm is tested on the IEEE33 distribution network with and without DGs, respectively. The parameters of DGs are shown in Table 1.

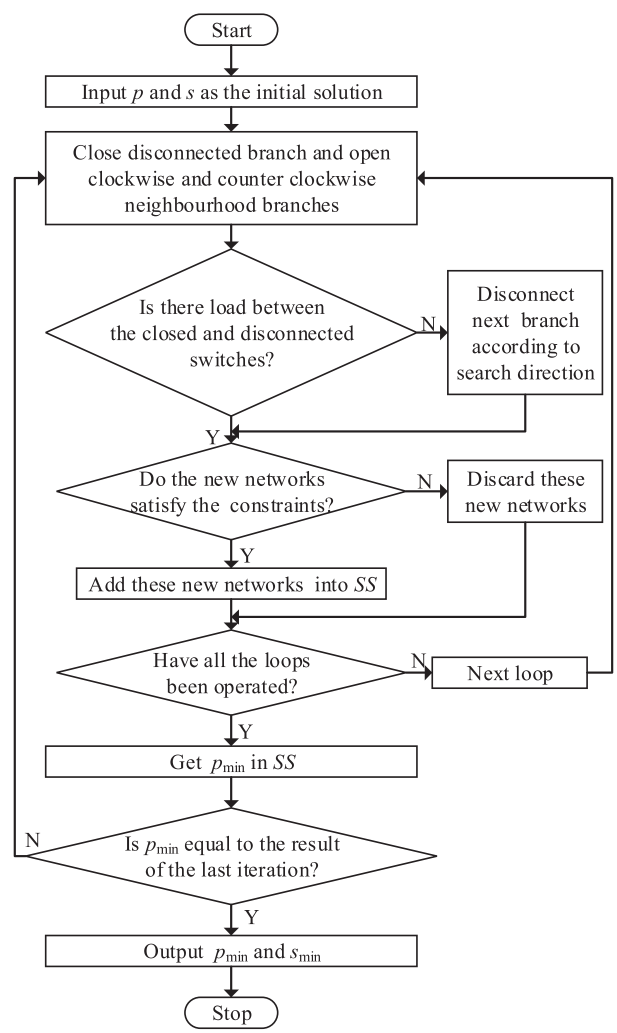

Figure 4. Flow chart of the second level reconfiguration based on VNS.

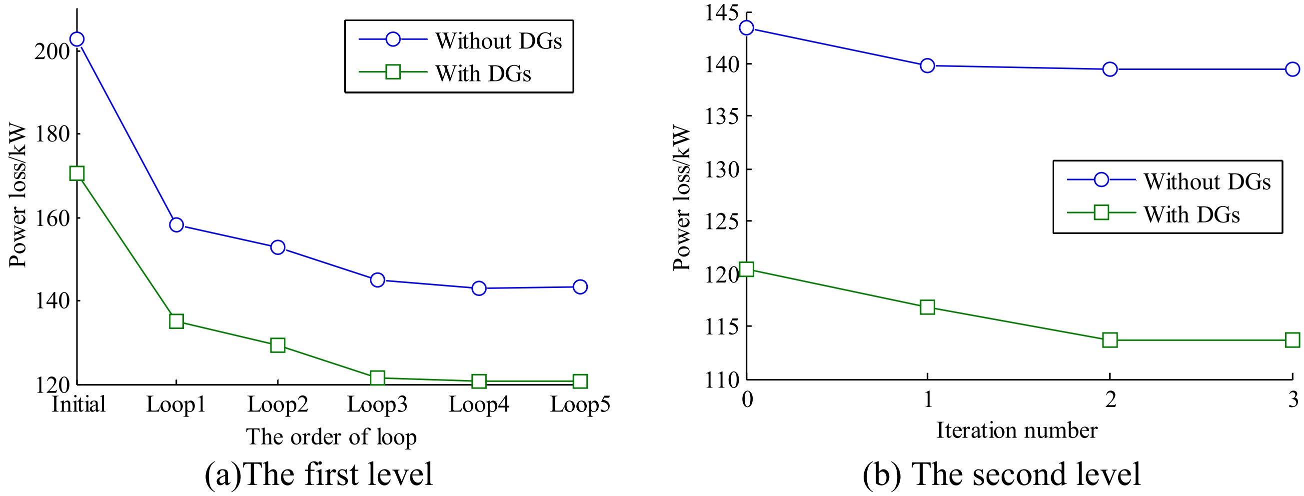

Figure 5. Convergence of two-level algorithm for IEEE33.

Table 1. Allocation and capacity of DGs.

Allocation bus	Capacity (kW)	Power factor
7	100	0.80
9	50	0.90
21	50	0.85
24	250	0.90

Table 2. Simulation results of IEEE33.

IEEE33	Item	Initial configuration	The first level	The second level
Without DGs	Tie switch	S_{33}, S_{34}, S_{35}, S_{36}, S_{37}	S_7, S_{13}, S_9, S_{32}, S_{28}	S_7, S_{14}, S_9, S_{32}, S_{37}
	P_{loss}(kW)	202.6471	143.4393	139.4731
	V_{min} (p.u.)	0.9133(18)	0.9408(33)	0.9378(32)
With DGs	Tie switch	S_{33}, S_{34}, S_{35}, S_{36}, S_{37}	S_6, S_{13}, S_9, S_{32}, S_{28}	S_7, S_{14}, S_9, S_{32}, S_{28}
	P_{loss} (kW)	170.6371	120.4888	113.6267
	V_{min} (p.u.)	0.9194(18)	0.9413(33)	0.9463(32)

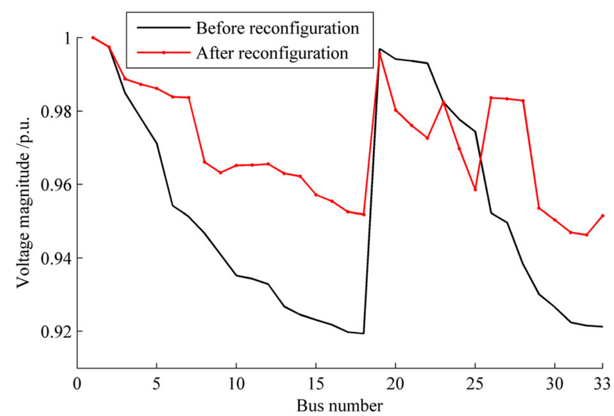

Figure 6. Voltage profiles of IEEE33 with DGs.

Simulation results are shown in Table 2. The power loss of IEEE33 without DGs is reduced from 202.6471 to 139.4731 kW. The lowest bus voltage is increased from 0.9133 to 0.9378 p.u. The optimal scheme after reconfiguration is [S_7, S_{14}, S_9, S_{32}, S_{37}]. The initial power loss of IEEE33 with DGs is 170.6371 kW. The lowest bus voltage is 0.9194 p.u. The optimal scheme after reconfiguration is [S_7, S_{14}, S_9, S_{32}, S_{28}], which has an active power loss of 113.6267 kW. And the minimum bus voltage is improved to 0.9463 p.u. Therefore, DG can effectively reduce the power loss and improve the voltage profile.

The convergence curves of the proposed algorithm are depicted in Figure 5. The new heuristic rule can greatly reduce the numbers of candidate switch and quickly determine the direction of power loss reduction. Consequently, it is clear that the power loss reduces rapidly in the first level reconfiguration. In the second level reconfiguration, VNS can eliminate the disadvantage that the BE cannot deal with the mutual influence between loops. The results continue to be optimized by VNS and only need two iterations to get the minimum power loss.

The voltage profiles of the IEEE33 with DGs before and after reconfiguration are shown in Figure 6. The loads on the higher voltage drop side of the tie switch are transferred to the other side in the first level reconfiguration. Therefore, it is observed that the voltage of most buses has been significantly improved.

4.2. Case 2

The second example system is the PG&69, 12.66 kV, 69 buses radial distribution network as shown in Figure 3. The normally closed sectionalizing switches are S_1–S_{68}, and the normally open tie switches are S_{69}–S_{73}. There are five loops in this system (loop 1 to loop 5) formed corresponding to each tie switch. The total active and reactive power loads are 3802 kW and 2964 kvar.

Table 3. Simulation results of PG&69.

Network	Item	Initial configuration	The first level	The second level
PG&69	Tie switch	S_{69}, S_{70}, S_{71}, S_{72}, S_{73}	S_9, S_{16}, S_{13}, S_{61}, S_{58}	S_{69}, S_{70}, S_{14}, S_{61}, S_{58}
	P_{loss} (kW)	226.4493	114.1652	100.9656
	V_{min} (p.u.)	0.9089(54)	0.9425(50)	0.9425(50)

The proposed algorithm is tested on the PG&69 distribution network. The results are shown in Table 3. It is observed that the optimal solution is [S_{69}, S_{70}, S_{14}, S_{61}, S_{58}], which has the power loss 100.9656 kW.

The convergence curves of the proposed algorithm are shown in Figure 7. It is observed that one only needs six iterations to find the optimal solutions.

The voltage profiles of the system before and after reconfiguration are shown in Figure 8. The minimum voltage increases from 0.9089 to 0.9425 p.u.

4.3. Algorithms comparison and performance analysis

To verify the stability of the proposed algorithm, case 1 is repeatedly solved 200 times. The best and average power loss, the minimum voltage and standard deviation (STD) are listed in Table 4, which are compared with GA (Tahboub et al., 2015), HSA (Rayapudi et al., 2011) and FWA (Mohamed Imran & Kowsalya, 2014). A smaller STD implies that most of the best results are close to the average.

From Table 4, one can note that both the proposed algorithm and GA obtain the best power loss. The slight difference between the results is due to the difference in power flow methods and accuracy. Although the minimum voltage of FWA is greater than the proposed algorithm, the solution of FWA is not the optimal. Minimum power loss as well as average power loss of the proposed method is 139.47 kW. Meanwhile, STD is 0, which is much smaller than other algorithms. In other words, the proposed algorithm must be able to obtain the optimal solution. Therefore, its stability is much higher than the other three algorithms. The reasons are as follows:

In the first level reconfiguration, the disconnected switches in every loop can make the maximum power loss and the direction of optimization is firmly consistent with the direction of power loss reduction. In the second level reconfiguration, the proposed algorithm only searches the neighbourhoods of disconnected switches. This is equivalent to applying perturbation to the current optimal result to prevent the proposed algorithm from falling into the local optimal solution effectively.

To demonstrate the rapidity of the proposed algorithm, case 2 is repeatedly solved 200 times. The best power loss, minimum voltage, CPU time and average iteration are listed in Table 5. And these results have been compared with the other two-level algorithms for

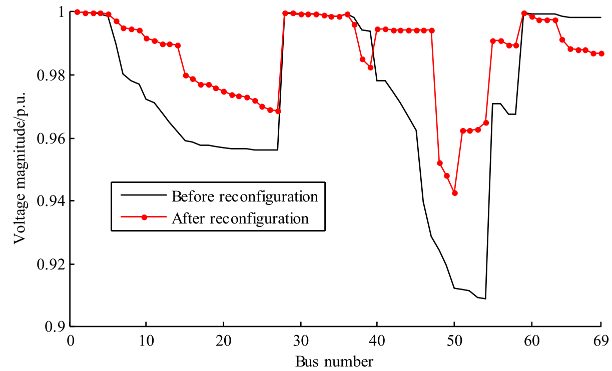

Figure 8. Voltage profiles of PG&69.

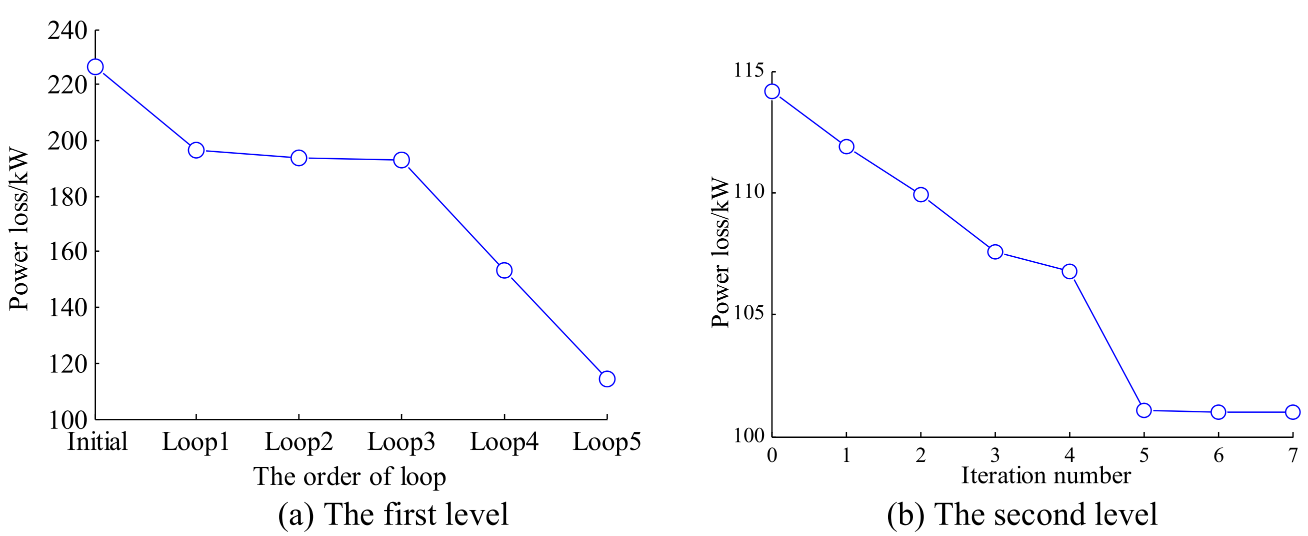

Figure 7. Convergence of two-level algorithm for PG&69.

Table 4. Perform analysis of algorithms for IEEE33.

Item		Initial configuration	GA (Tahboub et al., 2015)	HSA (Rayapudi et al., 2011)	FWA (Mohamed Imran & Kowsalya, 2014)	Proposed algorithm
Tie switch		$S_{33}, S_{34}, S_{35}, S_{36}, S_{37}$	$S_7, S_{14}, S_9, S_{32}, S_{37}$	$S_7, S_{14}, S_9, S_{36}, S_{37}$	$S_7, S_{14}, S_9, S_{32}, S_{28}$	$S_7, S_{14}, S_9, S_{32}, S_{37}$
Loss (kW)	Best	202.65	139.55	146.39	139.98	**139.47**
	average	—	166.2	152.33	145.63	**139.47**
V_{min} (p.u.)		0.9133	0.9378	0.9336	**0.9413**	0.9378
Average loss reduction		—	18.01	24.85	28.14	**31.18**
STD		—	14.53	11.28	5.49	**0**

Table 5. Perform analysis of algorithms for PG&69.

Item	Initial configuration	B&PSO (Lin et al., 2013)	C&CEA (Ou, Chen, & Jing, 2012)	Proposed algorithm
Tie switch	$S_{69}, S_{70}, S_{71}, S_{72}, S_{73}$	$S_{69}, S_{70}, S_{14}, S_{61}, S_{58}$	$S_{69}, S_{70}, S_{14}, S_{61}, S_{56}$	$S_{69}, S_{70}, S_{14}, S_{61}, S_{58}$
Power loss (kW)	226.45	**100.75**	101.02	100.97
V_{min} (p.u)	0.909	0.942	0.943	**0.943**
Newly generated networks in each iteration	—	≤ 50	≤ 50	$\leq$ **10**
Average iteration	—	43	25	**6**
Average computation time (s)	—	6.95	2.30	**0.69**

reconfiguration which are basic tree and particle swarm optimization (B&PSO) (Bai et al., 2016) and certain tree and co-evolution algorithm (C&CEA) (Xing & Sun, 2017).

From Table 5, all the three algorithms obtain the optimal solution. The disconnected switch is S_{56} of loop 4 in Bai et al. (2016), while it is S_{58} in Xing and Sun (2017) and this paper. Since there is no load between bus 46 and 47, the power loss of the disconnected switches S_{56}, S_{57} or S_{58} in loop 4 of PG&69 is the same. The proposed algorithm only needs six iterations to obtain the optimal solution and the average computation time is only 0.69 s. Therefore, the proposed algorithm can obtain the optimal solution faster than other algorithms. Its reasons are as follows:

In the first level reconfiguration, the improved BE greatly reduces the number of candidate switches. It takes only a single power flow calculation to obtain the switches of maximum power loss reduction in each loop. In the second level reconfiguration, it generates up to 10 new networks in each iteration, far less than other two algorithms. As a result, it significantly reduces the number of very time consuming power flow calculations. Therefore, the average computation time of the proposed algorithm is much less than the other two algorithms.

5. Conclusion

In this paper, a two-level algorithm is successfully applied to optimize the radical distribution network with the objective of power loss minimization. In the first level reconfiguration, it can quickly disconnect the switches of maximum power loss reduction based on the improved BE. In the second level reconfiguration, new neighbourhoods of disconnected switches are generated by the deterministic transform method. And then VNS obtains better results by searching the changing neighbourhoods. Simulations are carried on two test systems, and results are compared with other algorithms in the literature. The simulation results present that the proposed algorithm can converge to the global optimal solution. Numerical results of the IEEE33 distribution network demonstrate that the proposed algorithm is more stable than GA, HSA and FWA. Moreover, for another test system like the PG&69 distribution network, computational results show that the proposed algorithm converges to the optimal solution more quickly than B&PSO and C&CEA. To summarize, this method can be easily applied and adapted to the existing radial distribution networks.

Disclosure statement

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