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Optimizing location and size of distributed generators based on the metaheuristic algorithms for solving network reconfiguration problem

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Optimizing location and size of distributed generators based on the metaheuristic algorithms for solving network reconfiguration problem

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Abstract. This paper demonstrates the method of optimizing the location and size of the distributed generators with the aim of reducing active power loss by changing the state of the existing tie and sectionalizing switches on the distribution network. A new algorithm is proposed to solve the distribution network reconfiguration problem based on the Runner-root Algorithm (RRA). In the first stage, the Runner-root algorithm is applied to solve the reconfiguration problem, and the next stage of optimizing the new distribution network configuration takes into account the influence of the location and the size of the distributed generators. The calculation results show that the proposed method can simultaneously solve the problem of optimizing the location and size of distributed generators when reconfiguring the distribution network. The results of the comparison with other studies in the same distribution network system 69 nodes showed that the proposed method is highly effective and can be used for reference in the process of optimizing the operating mode of a distribution network.

Introduction

The distribution network (DN) system has a mesh configuration but always operates in a radial configuration [1]. The transfer of electricity from the power plant to the consumer will lead to losses in the transmission and distribution network. With the new structure of the distribution network, due to the participation of distributed generators (DG), the power flows do not only move from the transmission system but also circulates between parts of the distribution network back to the transmission network [2]. Therefore, the distribution network copes better with the supply of electricity to the consumer, ensuring the quality of electricity, the reliability of the power source, as well as reducing the load on the network, increasing the voltage at nodes, reducing power losses due to the enormous economic benefits and energy security of DGs. In recent years the demand for DG installations in the distribution network is developing rapidly [3] especially for DG large size using renewable energy sources such as wind and solar cell. However, with adverse environmental conditions, such as lack of wind or sun, can lead to a shortage of electricity in the transmission network for supply to the distribution network, the search for solutions to compensate for this power shortage is very important. One of the most effective solutions to this problem is optimizing location and size low-power generators in the DN [4]. In the last few years, several authors have proposed several methods for solving problems of optimizing location and size of DG for reducing energy losses in distribution network based on meta-heuristic algorithms like genetic algorithm (GA) [2,5],

particle swarm optimization algorithm (PSO) [6], hybrid learning-based optimization (HBO) [7], cuckoo search algorithm (CSA) [8], fireworks algorithm (FWA) [9], Harmony Search Algorithm (HSA)[10]. The authors only focused on optimizing the location and size of DGs without considering the configuration of the DN. In studies[11–13] it has been shown that solving the network reconfiguration problem is also an effective technique to reduce power loss in the DN system. This paper proposes the new method for determining the optimal location and size of the DG and working configurations is based on the Runner-root Algorithm (RRA). Problem for the optimal location and size of the DG in distribution network is presented in Section 2. The proposed method for solving DNR problem is presented in Section 3. Section 4 presents the calculated test results of the system and the conclusion is presented in Section 5.

Problem for the optimal location and size of the DG in distribution network
The distribution network reconfiguration problem will be demonstrated by a single-circuit diagram shown in Figure 1. If the switch on the branch (MN) is closed, the system operates in a mesh network configuration. Call currents in the branch are I_j. When the switch MN opens, implying that the current on the branch MO decreased and the current on the branches ON increases by I_{MN}. The power loss of the mesh network is ΔP_1 and the power loss of the radial network ΔP_2 is expressed by equations (1) and (2).
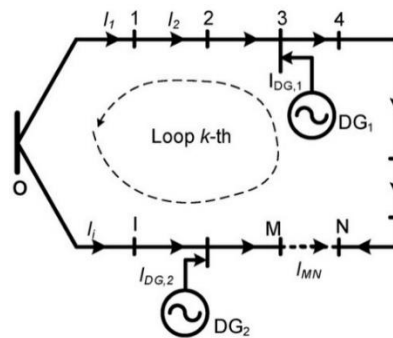

Figure 1. Single-circuit diagram distribution network.

$$\Delta P_1 = \sum_{\substack{j=1 \\ j\in MO}}^{N} R_j I_j^2 + R_{MN} I_{MN}^2 + \sum_{\substack{j=1 \\ j\in ON}}^{N} R_j \left(-I_j\right)^2 \tag{1}$$

$$\Delta P_2 = \sum_{\substack{j=1 \\ j\in MO}}^{N} R_j \left(I_j - I_{MN}\right)^2 + \sum_{\substack{j=1 \\ j\in ON}}^{N} R_j \left(I_j + I_{MN}\right)^2 \tag{2}$$

The change power loss in the distribution network is:

$$\Delta P_1 - \Delta P_2 = I_{MN}^2 R_{loop} - 2I_{MN} \cdot \left(\sum_{\substack{j=1 \\ j\in MO}}^{N} R_j I_j + R_{MN} I_{MN} + \sum_{\substack{j=1 \\ j\in ON}}^{N} R_j I_j \right) \tag{3}$$

Where:

$$R_{loop} = \sum_{\substack{j=1 \\ j\in MO}}^{N} R_j + R_{MN} + \sum_{\substack{j=1 \\ j\in ON}}^{N} R_j \tag{4}$$

From (3) it can be seen that in a mesh network, if there is a branch whose current is zero ($I_{MN} = 0$) then when opening this branch, the power loss in the system will be minimal, and the mesh network will become a radial network. The reality has shown that in the task of reconfiguring the distribution network to reduce power losses in the obtained optimal configuration, open switches are usually located on branches with very small currents if these switches are closed again.

Similarly, in a distribution network integrating DG, after determining the optimal location and size of the DG in a mesh network to minimize power loss; the value of power loss, in this case, will be the smallest that the system can achieve. Then, if the branches with the lowest current are identified for opening, the mesh network will become a radial network, and the power loss will be approximately equal to the power loss in a DG mesh network. In addition, the change in the network configuration does not affect the location and throughput of the DG, the mesh network has the problem of optimizing the location and throughput of the DG to minimize power loss. As soon as the optimum location and throughput of the DG are determined in the mesh network, open switches will be identified to maintain radial working conditions. The problem of determining the location and size of the DG, taking into account the reconfiguration of the network looks as follows:

The objective function for solving the DN reconfiguration problem is:

$$\Delta P = \sum_{j=1}^{N} R_j . (\frac{P_j^2 + Q_j^2}{U_j^2})$$ (5)

Where N is the number of the branches. R_i is the resistance of the jth branch. P_j and Q_j are the active power flow and the reactive power flow on the jth branch, respectively. U_j is the ending voltage of the jth branch. There constraints of this problem are:

1) The voltage in each node and the current in each branch must be within the allowable limits for each stage:

$$U_{min} \leq U_j \leq U_{Max}$$ (6)

$$I_j \leq I_{Max}$$ (7)

2) The radial configuration of the DN must be satisfied, and the load nodes must be connected to the power supply for the second stage.

3) The limits of distributed generating size should be maintained:

$$0 \leq P_{DG,k} \leq P_{DGMax,k}$$ (8)

The Runner-Root Algorithm for solving network reconfiguration problem

Runner- Root Algorithm is a newly developed algorithm inspired by the plants propagated through runners and root [14]. The RRA is equipped with two tools consisting of a random jump of mother plants and a re-initialization for reconnaissance. In the first case, every possible solution is a random change to go to any point in the search space. In the latter case, the algorithm will be restarted after a significant improvement in the fitness function after a certain number of generations. Two instruments equipped for exploitation and exploration mechanisms help the RRA to effectively find a global solution. To implement the algorithm, reference used the following three rules:

- The mother plants have generated the daughter in new locations through their runners to explore new resources.

- Plants generate roots (runner) and root hairs at random to use new resources in new locations.

-Subsidiaries grow rapidly and produce more new plants in rich resources. Otherwise, if the affiliated plants switch to a lack of resources, they will die.

Based on the mathematical explanation of the Runner-root Algorithm [15], the RRA method is implemented to optimize the location and size of the DG taking into account the network reconfiguration as follows.

Step 1: Initialization.

At the first step, the location and power of the DG are considered to be the mother plant. Mother plants are randomly initialized $(X_{mother} = [X_1, X_2, ..., X_{dim}])$ at the starting point of the algorithm as follows:

$$X_{mother,k} = round[X_{L,d} + rand \times (X_{H,d} - X_{L,d}], \tag{9}$$

Where: d_{im} is the number of variables or tie-switches, $X_{L,d} = 1$ and $X_{H,d}$ is equal to the length of the vector fundamental loop dth, a *rand* is a random number in range [0, 1], and $k = 1, ..., N; d = 1, ..., d_{im}$.

From the total of mother plants, the power flow is solving by using the Newton-Raphson method to obtain power losses, node voltages, and branch currents.

Step 2: Generation of daughter plants.

In this step, each subsidiary plant is generated by the corresponding mother plant.

$$X_{daughter,k}(i) = \begin{cases} X_{daughter,best}(i-1), k=1 \\ round\left[X_{daughter,k}(i) + d_{runner} \times rand \right], k=2,...,N \end{cases} \tag{10}$$

Step 3: Narrow search using large and small distances from the best plant.

In step 3, if there is no significant improvement in the best plant in two iterations $(i - 1)$ and i^{th}, which are presented by relative improvement index (RI), the RI is calculated by equation (11).

$$I = \left| \frac{f\left(X_{daughter,best}(i-1)\right) - f\left(X_{daughter,best}(i)\right)}{f\left(X_{daughter,best}(i-1)\right)} \right| \tag{11}$$

Where, $f(X_{daughter,best}(i-1))$ and $f(X_{daughter,best}(i))$ are the fitness value of the best plant in the generation $(i - 1)$ and generation i.

Narrow search with large distance: in this procedure N_{DG} of new plants are generated by adjusting the current best plant based on (12):

$$X_{perturbed,d} = round\left[vec\{1,1...,1,1,1 + d_{runner} \times rand_d, 1,...,1\} \times X_{best}(i) \right] \tag{12}$$

Where, $d = 1, ..., N_{DG}; vec\{1,1...,1,1,1 + d_{runner} \times rand_d, 1,...,1\}$ is a vector with element d updated to$(1 + d_{runner} \times rand_d)$and the remaining elements are equal to 1.

Narrow search with small distance: this procedure is, also appear new plants N DG, obtained using (13):

$$X_{perturbed,d} = round\left[vec\{1,1...,1,1,1 + d_{root} \times rand_d, 1,...,1\} \times X_{best}(i) \right] \tag{13}$$

From $(2 \times N_{DG})$ the new daughter plants, the DN bus data is updated, and the power flow is turned on to obtain the value of the fitness function based on equation (5), and the best solution $X_{best}(i)$ is being updated.

Step 4: Generate a new plant population.

At the final step of each generation, new mother plants for the next iteration are selected from the plants generated in step 3, based on the roulette wheel method.

Step 5: Network reconfiguration after installing distributed network.

From steps 1 to 4 (first stage), each radial configuration is represented by the location of the open switches. Therefore, the location of open switches is considered as a mother plant, and the mother

plants are randomly generated similarly as in step1. Where $d = 1,\dots,N_{SW}, X_{L,d} = 1$ and $X_{H,d}$ are the number of switches in the dth loop of the DN. Similar to step 2, each daughter plant is generated by the corresponding mother plant as (10). It is noticed that due to the fact that the population of daughter plants is represented by open switches, all daughter plants are rounded to an integer value. Then, the DN line data is updated, and the power flow is started to obtain the value of the fitness function based on (5). At the end of the step we obtain the best updated solution again.

   Step 6: Avoid local optimal solution.

   If there is no significant improvement in the best plant after the number of predefined iterations, the RRA is restarted by generating random uterine plants, similar to step 1 otherwise, the algorithm will move to step 2.

The calculated results of the proposed algorithm in DN 69 nodes system
The proposed method was evaluated on the distribution network with 69 nodes, includes 73 branches and 5 tie switches [16]. The system has three DGs with a maximum power of 2 MW. The proposed method is implemented in software MATLAB. The proposed method is also implemented and compared with the proposed method. The RRA parameters are applied to the system presented in Table 1. The performance of the proposed approach in the system of 69 nodes is presented in Table 2.

Table 1. RRA parameters for distribution network 69 nodes system.

	RRA	Simultaneous
Mother plants	30	30
$iter_{Max}$	150	1000
tol	5	11
d_{runner}	4	4
d_{root}	2	2
$Stall_{Max}$	50	50

   From Table 2 in the initial configuration, the power loss is 224.89 kW, which is reduced to 28.8875 kW and 39.31 kW when solving the problem. It can be seen that, in comparison between the method of simultaneous reconfiguration and the placement of DG, these results almost coincide with the results obtained using the method of simultaneous reconfiguration and placement of DG. The minimum power loss obtained by the method of simultaneous reconfiguration and placement of the DG is 35.1929 kW, which is only 4.1171 kW lower than the result obtained by the proposed method.

Table 2. The performance of the proposed methodology in the system with 69 nodes.

	Initial	The proposed method base on RRA	Simultaneous entry and DGs based on RRA
Open Switches	69, 70, 71, 72, 73	69, 70, 12, 55, 63	69, 70, 14, 55, 61
DG size (MW)	-	1.6175, 0.7710, 0.6752	0.5161, 1.4517, 0.5369
In bus number	-	61, 50, 21	64, 61, 11
Power loss (kW)	224.89	39.31	35.1929
% Loss reduction	-	82,52	84.35
Max fitness	-	42,8777	48,622
Average fitness	-	40,5443	40,3116

	Initial	The proposed method base on RRA	Simultaneous entry and DGs based on RRA
STD fitness	-	1,46845	3.25004
Average iterations	-	71.05	807.15

In addition, Table 2 shows that the average values of the fitness function are closer to the minimum value than in the method of simultaneous reconfiguration and placement of DGs.
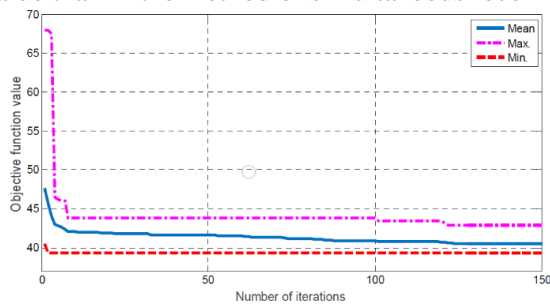

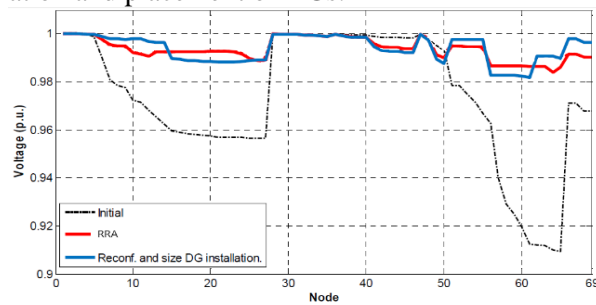**Figure 2.** RRA convergence for 50 independent runs for a 69-node test system.

Figure 3. Voltage profiles in three cases of a system of 69 nodes.

The behavior of convergence is presented in Figure 2. The voltage profiles in the three cases are compared and shown in Figure 3. As shown in this figure, it is observed that the voltage value in all nodes was increased after using the proposed method, and the voltage profile is almost the same as the voltage profile of simultaneous reconfiguration and the method of locating DGs.

Table 3. The comparison results in a system of 69 nodes with various methods.

	The proposed method	CSA [8]	FWA [9]	HSA [10]
Open Switches	69, 70, 12, 55, 63	69, 70, 14, 58, 61	69, 70, 13, 55, 63	69, 17, 13, 58, 61
DG size (MW)	1.6175, 0.7710, 0.6752	0.5413, 0.5536, 1.7240	1.1272, 0.2750, 0.4159	1.0666, 0.3525, 0.4257
In bus number	61, 50, 21	11, 65, 61	61, 62, 65	61, 60, 62
Power loss (kW)	39.31	37.02	39.25	40.3
% Loss reduction	82,52	83.54	82.55	82.08

The results of a comparison with CSA [8], FWA [9], and HSA [10] are presented in Table 3. The results showed that in the network system of 69 nodes, the decrease in percent losses for the RRA method is 1.02 higher than the result obtained by the CSA [8], and these results almost coincide with the results obtained using the FWA method with 82.55% and compared with HSA, this is better.

Conclusions

In this paper, the RRA-based method was successfully applied to optimize the location and size of the DG with regard to network reconfiguration. The main idea of the proposed method consists of optimizing the location and size of the DG in the distribution networks with feedback and optimizing the working configuration of the DN. The calculation results show that the proposed method is able to determine the optimal solution and is better than the compared methods in the literature. In addition, the results of the calculations also showed that the proposed method allows solving the problem faster compared to the method of reconfiguration of simultaneous location and the size of the DG.

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