Signal Processing and Renewable Energy
September 2017, (pp.1-11)
ISSN: 2588-7327

Distribution Network Reconfiguration Study Using the Gravitational Search Algorithm

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Abstract

In this paper, the electrical distribution network reconfiguration to achieve loss reduction, load balancing and improve voltage profile in the presence of Distributed Generation (DG) with the gravitational search algorithm (GSA), is investigated. By choosing a 33-bus IEEE sample network and running a computer simulation on it, it is observed that the results of this rearrangement are comparable with similar papers.

Keywords: Reconfiguration, Distributed Generation, Gravitational Search Algorithm

1. INTRODUCTION

The electrical power system consists of three major components: generation (power plant), transmission (transmission lines) and distribution (energy distribution systems). Thus, the generated powers at the power plants reach by the transmission and distribution lines to the utilities. The distribution network is the most expensive part of the electrical power system, so one -third of the power system investment belongs to the distribution network; on the other hand, due to the voltage level, the most losses are also related to this part of the power system [1].

The electrical distribution network reconfiguration is indeed the process of changing the structure of the network by opening and closing the keys. Given the large number of keys in real networks, the number of possible cases for opening and closing keys is very high. Therefore, the key problem in solving the problem of distribution network reconfiguration is the best switching status at the fastest possible time. In fact, in various methods of reconfiguration, we seek to find methods to achieve the desired goal.

The problem of distribution network reconfiguration is one or multi-objective optimization problem. The primary purpose of this system is to reduce total system losses. Other reconfiguration objectives include load balancing, improved voltage profiles, improved reliability and network retrieval and

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etc. take into account network constraints such as radiation network, current and power-consuming equipment, Voltage drop range, and so on.

For the first time in 1975, Merlin et al. [2] presented a method of reconfiguration for loss reduction. In 1988, Civanlar et al. [3] presented a new hysteresis method with an approximate formula for loss reduction, and this year Shir Mohammadi et al. [4] presented a distributed load distribution method which this method and civanlar method are both based on many next hysteresis methods. In the same year, Baran et al. [5] developed the load balancing objective function with the development of the civanlar method and introduced the Distflow load method.

Since, many methods have been proposed for reconfiguration that began with simple and primitive methods and they have been improved with more intelligent and sophisticated methods such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Steel Plating (SA), Artificial Neural Networks, Expert Systems, Ant Colony Optimization algorithm (ACO), Tabu Search algorithm (TS), etc [6-13] in the presence of Distributed Generation.

In the following, the mathematical model of the distribution network reconfiguration problem, Gravitational Search Algorithm, calculation method, case study and comparison of the results are described.

2. FORMULATION OF THE PROBLEM

2.1. Loss Reduction

Loss reduction in the power distribution system is one of the biggest challenges for power engineers. The network reconfiguration is the choice of the appropriate network topology structure to reduce losses. In this paper, network reconfiguration for loss reduction is formulated as follows:

$$P_{loss} = \sum_{i=1}^{n_b} r_i \frac{p_i^2 + q_i^2}{V_i^2} \tag{1}$$

where p_i is the active power output line from i-bus, q_i is the reactive power output line from i-bus, n_b is the Number of branch, r_i is the resistance i-bus and v_i is the Voltage domain i-bus.

2.2. Load Balancing

In the distribution system, the reconfiguration of feeders can change the system topology under normal and abnormal operating conditions to eliminate overload. Load imbalance over the feeder is one of the major causes of increased the loss of the system.

The scheduling of the feeder reconfiguration for load balancing which is made by switching will reduce system losses and increase the flexibility of operation by equally distributing reserve capacity among main transformers. For load balancing, the load balancing index is defined by the following formula that should be minimized:

$$LB_i = \sum_{i=1}^{n_t} \left(\frac{S_i}{S_i^{\max}} \right)^2 = \sum_{i=1}^{n_b} \frac{p_i^2 + q_i^2}{S_i^{\max 2}} \tag{2}$$

where S_i is the Mixed power at i-bus and $S_i^{\max}$ is the Maximum capacity of i-branch.

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2.3. Improve the Voltage Profile

To improve the voltage profile, the voltage quality indicator is defined as:

$$\sum_{i=1}^{n_b} \left| V_i - V_{rat} \right| \tag{3}$$

Where v_{rat} is the Nominal voltage i-bus.

2.4. Problem Constraints

The first constraint is that the network with the final arrangement is radial. In addition, they are fed all the time and the voltage domains of the bus and current branches are within the allowed range of:

$$V_{\min}^{i} \le V_i \le V_{\max}^{i} \tag{4}$$

$$|I_i| \le I_{\max}^{i} \tag{5}$$

where $V_i^{\max}$ is the maximum voltage i-bus, $V_i^{\min}$ is the minimum voltage i-bus, I_i is the flow i-branch and $I_i^{\max}$ is the maximum flow i-branch.

$$\sum_{i=1}^{n_b} |\alpha_L - \alpha_\circ| \le n_{SA} \tag{6}$$

where α_L is the Switching status after reconfiguration, $\alpha_\circ$ is the Current status of the key and n_{SA} is the number of allowed switching.

3. GRAVITATIONAL SEARCH ALGORITHM

In the GSA algorithm, optimization is done by gravitational and motion laws in a discrete-time synthetic system [11]. The system environment is the same as the definition of the problem. Under gravity law, each mass perceives the location and condition of other masses through gravitational energy. Therefore, this force can be used as a tool for the exchange of information. From the designed optimizer, it can be used to solve the optimization problem which each problem is defined as a position in a defined space and its similarity with other problem solutions can be expressed as a space. The number of masses are determined according to the objective function.

In the first step, the system space is determined. The environment contains a multidimensional coordinate system in the problem definition space. Every point in space is a solution to the problem. The search agents are a set of objects. Each mass has three characteristics:

a) Mass situation, b) mass gravity, c) mass inertia

The above-mentioned masses are derived from the concepts of active gravitational gravity and mass inertia in physics. In physics, active gravitational gravity is a measure of gravity intensity energy around an object and the mass of inertia is a measure of the resistance of the object to motion. These two characteristics cannot be equal to each other in contrary to reality and their amount is determined by the fitness of each mass. The position of mass is a point in space that is the answer of the problem.

After the formation of the system, the governing rules are specified. We assume that only the law of gravitation and laws of motion dominate. The general form of these laws are almost similar to the laws of nature and are defined as follows.

Gravity rule: Each mass in the artificial system attracts all other masses to itself. The amount of this force is proportional to its gravitational mass and reverse the distance between the two masses.

Motion rules: The current velocity of each mass is equal to the sum of the coefficients of the previous velocity of the mass and its change in velocity. The change in speed or acceleration of each mass equals the force applied to it, divided by the inertia mass.

Now imagine the system as a set of mass m. The position of each mass is a point of space, which is the answer to the problem.

The position of the dimensional d of the mass i is shown with x_i^d .

$$X_i = \left(x_i^1, \ldots, x_i^d, \ldots, x_i^n\right) \tag{7}$$

In this system, at time t, a mass of force $F_{ij}^d(t)$ is applied to each mass i by mass j in the direction d of d. The value of this force is calculated according to (8). Where mg_i is the gravitational mass j, G(t) is the gravitational constant at time t and R_{ij} the distance between the second mass i and j. Euclidean distance (norm 2) has been used to determine the distance between masses.

In (8), ε is a very small number. The force on mass i in the direction of dimension d at time t is equal to the sum of all the forces that other masses of the system impose on the mass.

According to Newton's second law, each mass accelerates in the direction of dimension d, which is proportional to the mass force in that direction, in terms of the mass of the inertia mass stated in relation (11). In this case, the acceleration of mass i in the direction of dimension d at time t and the mass of inertia mass i are shown respectively with $a_i^d(t)$ and mi_i .

The velocity of each mass is equal to the sum of the coefficients of the current velocity and mass acceleration of the class of relation (12). The new position of dimension d from mass i is calculated in relation (13).

r_i and r_j , random numbers are distributed uniformly in [1 and 0], which are used to maintain the randomness of the search.

Equation (14) is used to adjust the gravity coefficient. In this case, the gravity constant decreases exponentially. The value of α is 20 and the value of β increases linearly from 1 to 3.

$$mg_i = \frac{f_i t_i - worst(t)}{best(t) - worst(t)} \tag{8}$$

$$mi_i = 1 + mg_i \tag{9}$$

To regulate the masses, the object function mapping of the masses are used, so that more masses are attributed to objects with better merit.

In these relations, $F_i t_i(t)$ the degree of fitness of mass i at time t is indicated. We can use the following relationships to calculate the best and worst in the minimization questions.

$$\begin{gathered} best(t) = \min f_i t_j \\ j = \{1, \ldots, m\} \end{gathered} \tag{10}$$

$$\begin{gathered} worst(t) = \max f_i t_i(t) \\ j = \{1, \ldots, m\} \end{gathered} \tag{11}$$

In Fig. 1, the pseudo-code algorithm is presented.

4. ALCULATION METHOD

The calculation method begins by closing all the keys in the distribution system and converting it to a number of loops. Therefore, the reconfiguration problem turns into the right key selection in each loop to remain in the radial network. Therefore, despite changing network topology, the total number of interface keys remains constant.

Impedance matrix based methods have been used to solve the load distribution. In this method, using the collector property, the voltage drop due to the network loads and the final voltage of the nodes are obtained. Outstanding features include high convergence

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1) Set the system environment and initializing.
2) Initial placement of objects.
3) Evaluation of objects.
4) Update parameters G, best, worst, mi and mg.
5) Calculate the force applied to each mass.
6) Calculate the acceleration and speed of each mass.
7) Update the position of the objects.
8) If the condition is not met, go to step 3.
9) End.
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Fig. 1. Pseudo-code of GSA algorithm.

speeds, low computational volume, low memory requirements and less sensitivity to changes R/X .

A) The simultaneous multiprocessor retrieval solution is obtained using the Pareto optimal solution method. In this method, the set of non-dominated responses are stored in a storage medium and are represented as a graph.

The prevailing condition of the answer:

B) For all target functions, the value of the target functions for the answer X_1 are less than the answer X_2.

$$\forall i \in \{1,2,...,n\}\,,\ f_i(X_1) \le f_i(X_2) \tag{12}$$

$$\exists j \in \{1,2,...,n\}\,,\ f_j(X_1) \le f_j(X_2) \tag{13}$$

At least for a target function, the value of the target function of the answer X_1 is less than the answer X_2.

$$N\mu(j)=\frac{\sum_{i=1}^{n}\omega_i.\mu_{f_i(X_j)}}{\sum_{j=1}^{m}\sum_{i=1}^{n}\omega_i.\mu_{f_i(X_j)}} \qquad \begin{matrix} i=1,2,...,n \\ j=1,2,...,N_{repository} \end{matrix} \tag{14}$$

If X_1 the answer X_2 is defeated, X_1 is stored as a dominant answer in the cache. The answers in the cache contain the Pareto curve. If the answer to be placed in the cache, you must have the following conditions:

- The storage is not full.
- Do not break the target by any of the answers in the cache.
- A fuzzy clustering method is used to arrive at a final answer that has good compromise with all target functions. This method obtains the same method as the fuzzy interaction method for each of the answers in the fuzzy membership function saver. Then, for the membership functions obtained, we construct the normalized vector.

$$N\mu(j)=\frac{\sum_{i=1}^{n}\omega_i.\mu_{f_i(X_j)}}{\sum_{j=1}^{m}\sum_{i=1}^{n}\omega_i.\mu_{f_i(X_j)}} \qquad \begin{matrix} i=1,2,...,n \\ j=1,2,...,N_{repository} \end{matrix} \tag{15}$$

In fact, this normalized vector is fuzzy. Which is formed for the membership functions obtained for each objective function. In this case, j is the number of replies in the cache, and w_i is the the I-factor target, which is usually equal to 1. In the following, we arrange the answers based on the value obtained for the normalized vector in ascending order, and then the best answer is obtained.

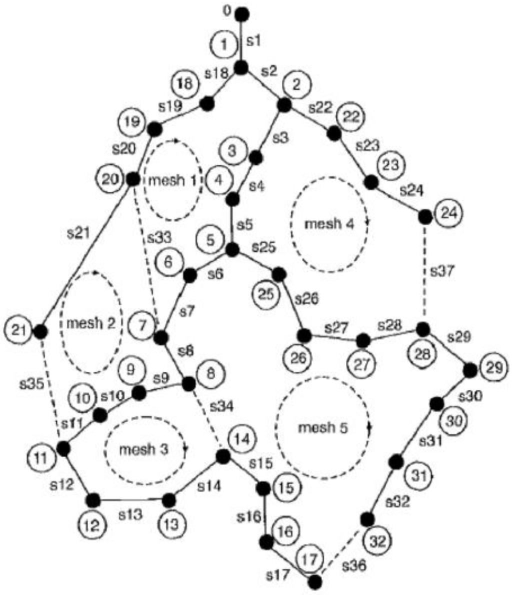


Fig. 2. 33-bus distribution system.

5. CASE STUDY AND OMPARISON OF RESULTS

The Case study of test network is the same as the 33-bus IEEE distribution network is shown in Fig. 2. Table 1 shows the position and capacity of the installed DGs for the 33 Bus system.

The parameters of the 33-bus distribution system are presented in Table 2. The distribution system studied includes a transformer, 32 busbar, and 5 interface keys. The active and reactive power of the total load of the system is 5048.26 kv and 2547.26 kW, respectively. In Fig. 1, the numbers inside the circle and the numbers next to 'S' indicate the number of the node and line key, respectively.

In addition, distanced lines show the open interface keys for initial alignment. In comparison with the paper [15], loss reduction and load balancing in the presence of DG and without DG in our study are considered, while the improvement of the voltage profile is also examined before and after the reconfiguration in each case. The proposed method is run with the MATLAB program and runs on a pentium-IV 3.4GHz computer.

Tables 3, 4, 5 and 6 show the comparison of performance with article [15]. Also, the voltage profile before and after the reconfiguration is shown in Fig.s 3, 4, 5, and 6, respectively.

The results of our study on the distribution system of 33 -bus in the presence of DG and without DG in comparison with the paper [15] and the methods stated in it, indicate that in one-goal reconfiguration, better and more positive results are obtained.

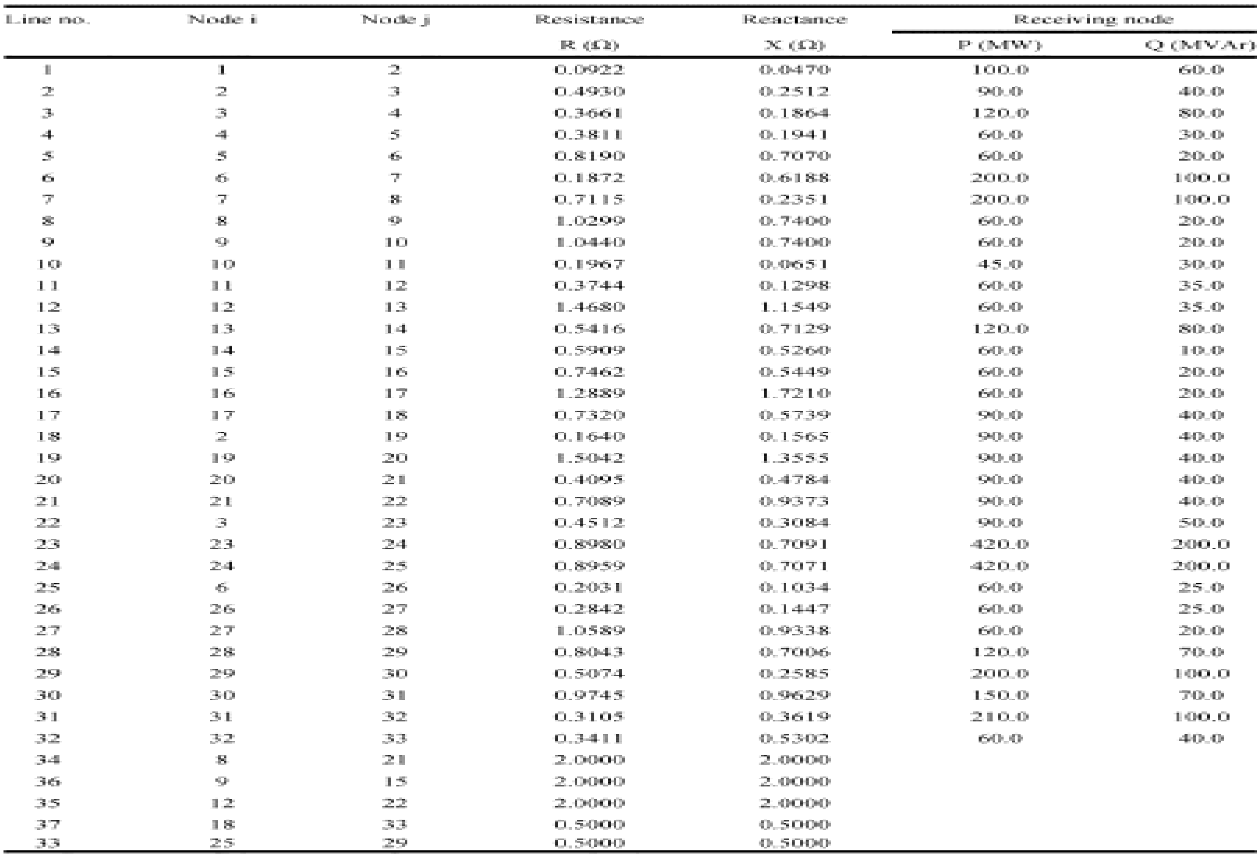
In addition to one-goal reconfiguration, multi-objective reconfiguration is considered in our study with consideration of loss reduction and load balancing simultaneously. Also, the voltage profile is shown before and after the reconfiguration.

Table 7 and Fig.s 7 and 8 show, respectively, the results of multi-objective reconfiguration and the voltage profile curve before and after reconfiguration in this case. Meanwhile, the multi-objective reconfiguration response obtained using the Pareto method is shown in Fig. 9 and 10.

Table 1. ***Location and capacity of DG installation.***

node	capacity
3	50.08
6	100.09
24	200.09
29	100.1

Table 2. ***Information and Parameters of the 33-Bus Distribution System.***



Line no.	Node i	Node j	Resistance R (Ω)	Reactance X (Ω)	Receiving node P (MW)	Receiving node Q (MVAr)
1	1	2	0.0922	0.0470	100.0	60.0
2	2	3	0.4930	0.2512	90.0	40.0
3	3	4	0.3661	0.1864	120.0	80.0
4	4	5	0.3811	0.1941	60.0	30.0
5	5	6	0.8190	0.7070	60.0	20.0
6	6	7	0.1872	0.6188	200.0	100.0
7	7	8	0.7115	0.2351	200.0	100.0
8	8	9	1.0299	0.7400	60.0	20.0
9	9	10	1.0440	0.7400	60.0	20.0
10	10	11	0.1967	0.0651	45.0	30.0
11	11	12	0.3744	0.1298	60.0	35.0
12	12	13	1.4680	1.1549	60.0	35.0
13	13	14	0.5416	0.7129	120.0	80.0
14	14	15	0.5909	0.5260	60.0	10.0
15	15	16	0.7462	0.5449	60.0	20.0
16	16	17	1.2889	1.7210	60.0	20.0
17	17	18	0.7320	0.5739	90.0	40.0
18	2	19	0.1640	0.1565	90.0	40.0
19	19	20	1.5042	1.3555	90.0	40.0
20	20	21	0.4095	0.4784	90.0	40.0
21	21	22	0.7089	0.9373	90.0	40.0
22	3	23	0.4512	0.3084	90.0	50.0
23	23	24	0.8980	0.7091	420.0	200.0
24	24	25	0.8959	0.7071	420.0	200.0
25	6	26	0.2031	0.1034	60.0	25.0
26	26	27	0.2842	0.1447	60.0	25.0
27	27	28	1.0589	0.9338	60.0	20.0
28	28	29	0.8043	0.7006	120.0	70.0
29	29	30	0.5074	0.2585	200.0	100.0
30	30	31	0.9745	0.9629	150.0	70.0
31	31	32	0.3105	0.3619	210.0	100.0
32	32	33	0.3411	0.5302	60.0	40.0
34	8	21	2.0000	2.0000		
36	9	15	2.0000	2.0000		
35	12	22	2.0000	2.0000		
37	18	33	0.5000	0.5000		
33	25	29	0.5000	0.5000		

Table 3. ***Comparison of the performance of the loss reduction network of 33-bus without DG.***

	Open keys	**Losses**	
		Percentage decrease	**kw**
Primary	$S_{33}, S_{34}, S_{35}, S_{36}, S_{37}$	17.711	164
GA	$S_7, S_9, S_{14}, S_{28}, S_{32}$	43.803	112
AS	$S_6, S_9, S_{14}, S_{26}, S_{31}$	35.022	129.5
ACS	$S_7, S_9, S_{14}, S_{28}, S_{32}$	44.625	110.26
GSA	$S_7, S_9, S_{14}, S_{32}, S_{37}$	49.697	*100.2521*

Table 4. ***Comparison of Load Balance Function of 33-Bus Network Distribution without DG.***

	Open keys	Load Balancing Index	
		Percentage decrease	Index
Primary	$S_{33}, S_{34}, S_{35}, S_{36}, S_{37}$	-	148.1634
AS	$S_6, S_9, S_{12}, S_{28}, S_{31}$	25.0.65	111.0251
ACS	$S_7, S_{11}, S_{14}, S_{28}, S_{31}$	28.57	105.8324
GSA	$S_7, S_{37}, S_{34}, S_{21}, S_{32}$	56.353	*64.6682*

Table 5. ***Comparison of Load Balance Function of the 33-Bus Net Distribution Network in the presence of DG.***

	Open keys	Load Balancing Index	
		Percentage decrease	Index
Primary	$S_{33}, S_{34}, S_{35}, S_{36}, S_{37}$	-	118.9525
AS	$S_6, S_9, S_{12}, S_{28}, S_{31}$	24.413	89.9104
ACS	$S_7, S_{11}, S_{14}, S_{28}, S_{31}$	29.493	83.8635
GSA	$S_{17}, S_{37}, S_{34}, S_{21}, S_{33}$	48.131	*61.6991*

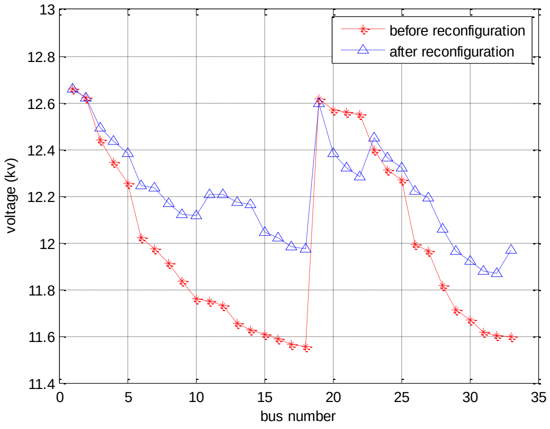


Fig. 3. Comparison of the voltage profile curve before and after the reconfiguration with the aim of reducing losses without DG.

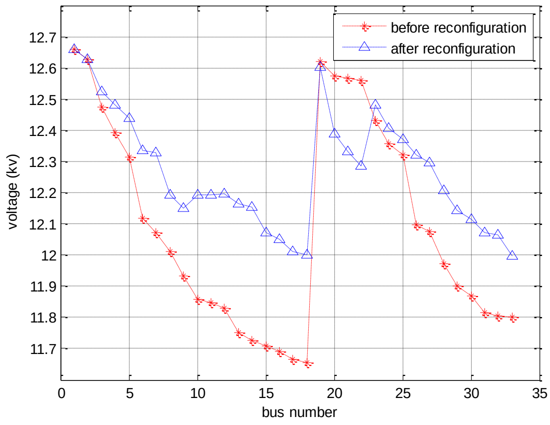
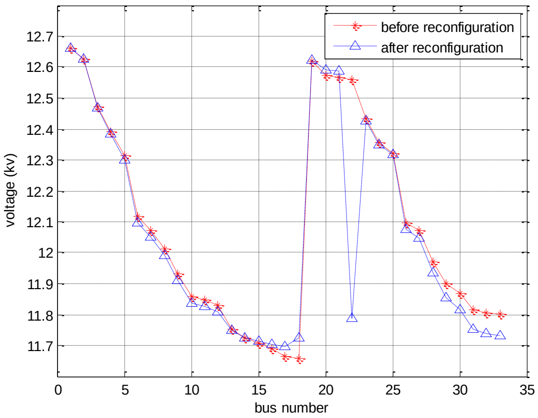


Fig. 4. Comparison of the voltage profile curve before and after the reconfiguration with the aim of reducing the losses in the presence of DG.

Table 6. ***Distribution network simultaneous reconfiguration of 33-bus without DG presence.***

Configuration	**Open keys**	**Loss Reduction(kw)**	**Load Balancing**
Primary	$S_{33}, S_{34}, S_{35}, S_{36}, S_{37}$	199.3	148.1634
Without DG	$S_{37}, S_9, S_{34}, S_{33}, S_{31}$	153.9211	72.5201
Percentage reduction without DG		22.769	51.0539
With DG	$S_{27}, S_{33}, S_{34}, S_{35}, S_{36}$	130.7744	66.6654
Percentage reduction with DG		34.3831	*55.0054*



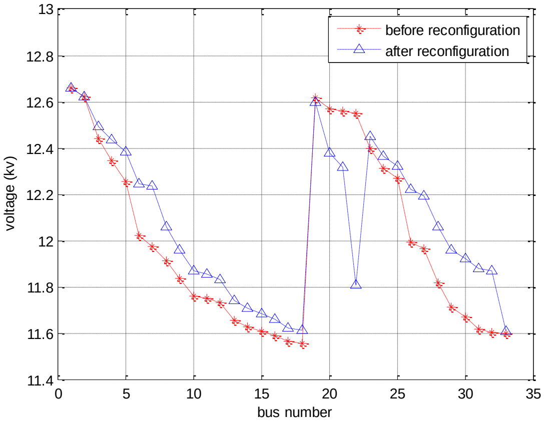
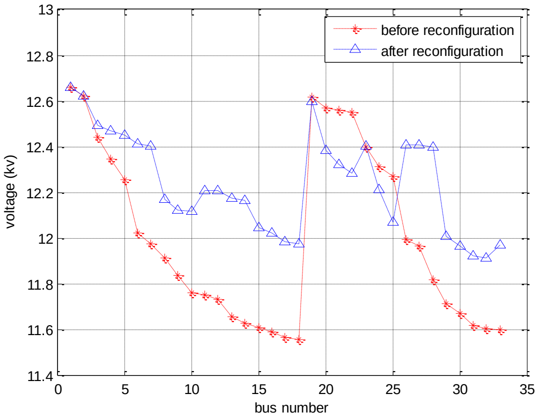


Fig. 5. Comparison of the voltage profile curve before and after the reconfiguration with the aim of load balancing without DG.

Fig. 6. Comparison of the voltage profile curve before and after the reconfiguration with the load balancing target in DG presence.



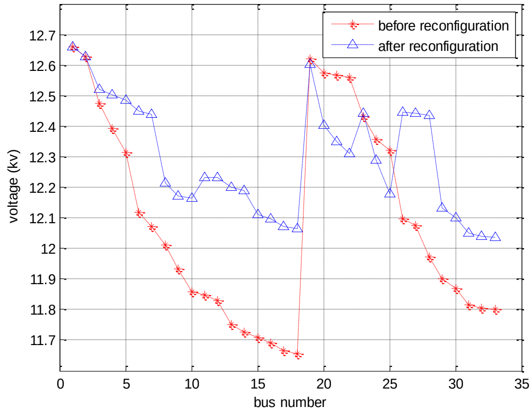
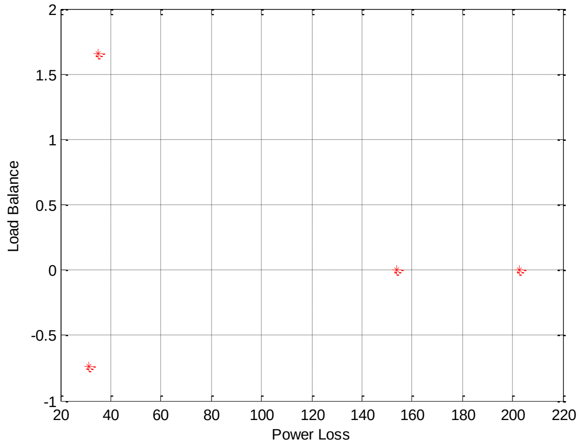


Fig. 7: curve of Voltage profile before and after simultaneous rearrangement without DG.

Fig. 8: Voltage profile curve before and after simultaneous reconfiguration in DG presence.



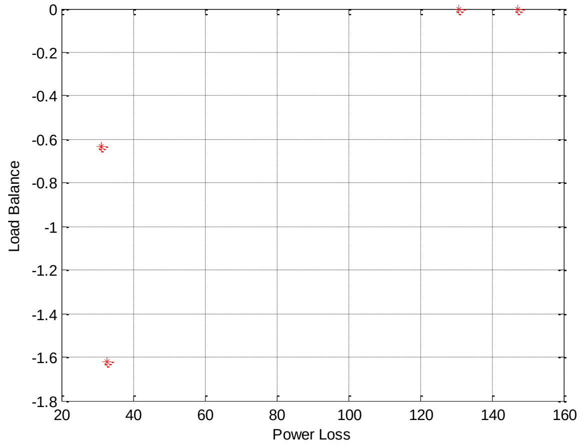


Fig. 9: Pareto's response to simultaneous reconfiguration without DG.

Fig. 10: Pareto's response to simultaneous reconfiguration in the presence of DG.

6. CONCLUSION

In this paper, for the first time the study of the distribution network reconfiguration of 33-bus with and without the DG has been carried out with the new GSA algorithm to investigate, such as loss reduction, load balancing and improve the voltage profile. As seen, using the GSA algorithm are obtained better results than the other algorithms.

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