DETERMINATION OF OPTIMAL PLACEMENT AND SIZING OF DISTRIBUTED GENERATION IN DISTRIBUTION NETWORKS IN ORDER TO IMPROVE THE RELIABILITY USING GLOBAL CONFIRMING PARTICLE SWARM OPTIMIZATION (GCPSO)

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ABSTRACT: *This paper presents reliability improvement in distribution power systems. There are good features coming by the emergence of Distributed generation (DG) in power systems such as increase in reliability, loss reduction, voltage profile improvement and etc. In this paper, a method is presented based on Global Confirming Particle Swarm Optimization (GCPSO) in which objective function is defined in a way to minimize the combinatorial indices of reliability. In this method, Genetic algorithm is combined with the PSO for not trapping it in local optimum points. Besides, it helps the algorithm to run from these points and reach to global optimum points while convergence speed remains the same. Efficiency of the proposed method is verified on standard 33-bus IEEE system.*

Keywords: Distributed Generation (DG) units, Distribution network, Reliability, Global Confirming Particle Swarm Optimization (GCPSO), Analytical method.

INTRODUCTION

In past decades, distribution networks have paid less attention comparing with transmission and generation sections in a way the distribution section was the weakest link between supply and customers. Besides, statistics and reports show that the main reason for cutting out is incidences in distribution systems [1,2]. In some countries, the quote for cutting out due to distribution networks reaches more than seventh percent. This justifies a thorough research about reliability in such networks. On the other side, reliability is an inherent feature and criterion of systems which evaluates their ability in supplying pertained electricity to the final customers.

Utilizing small generation units called the "distributed generation" that are connected to the distribution networks has increased over the past years due to environmental pollutions, problems relating to the construction of new transmission lines, technology enchantments in making economic generation units in small scale instead of large scale units and privatization of this industry. Therefore, existence of generator in distribution network affects the transmitted power, load voltage condition and electric network devices, and this can affect the performance parameters of the system positively or negatively[3,4]. Optimal placement and sizing of distributed generation on reliability of distribution networks are presented to assure positive effects are made to the system. There have been lots of studies and researches related to evaluation of reliability in distribution systems where all of them focus on approaches to calculate the reliability indices in the [5,6,7,8]. Hence, in this paper a new method is presented for optimal placement and sizing of distributed generation resources based on minimizing the combinatorial indices of reliability considering technical and electrical constraints. To do this, Global Confirming Particle Swarm Optimization (GCPSO) is used while convergence and speed are remained the same.

2. Effect of distributed generation (DG) on reliability of power systems

Based on the polls carried out in US and Canada, it is understood that reliability of electricity is the most important factor that customers are sensitive to after electricity price [9].

From conceptual point of view, reliability is an inherent feature and criterion for describing the ability of systems in doing pertained performances and duties. The most important performance of power system is to supply electricity of final customers. Hence, important criteria are those can evaluate the overall performance [1,2]. Unfortunately, as possession of most DGs is in the hand of customers, distribution companies have lower control on size and location of these DGs. Therefore, there should be a comprehensive and general standard for control, installation and placement of DGs in order to avoid negative influences on parameters of system [5,6,7,8].

Despite all advantages of DGs, negative effects of such devices are to be considered in distribution network which the most important concerns are related to voltage level and protection coordination [11].

From technical point of view, duty of distribution system consists of receiving the energy from transmission system and delivering it to final customers with keeping proper quality (in terms of voltage, frequency, harmonics and etc) and agreeable level of reliability (i.e. number and duration of cut out are low). However, it is possible that DGs can affect the reliability of power system negatively due to false placement or higher capacity of DGs with respect to the maximum inject-able power in bus bars. Therefore, optimal placement of DGs will improve the reliability.

3. Determining the objective function

3.1. evaluating the reliability of the distribution system

The important characteristic of distribution systems is that they are directly connected to customers and consumers of electricity. This characteristic has shown its effect in definition of reliability indices of such systems which generally these indices are defined by customers.

These indices are defined in Table 1 It is noted that these indices can be calculated for the whole system or any part of it or even an specific feeder.

It is very important to cite that three parameters play the main role in defining such indices:

λ failure rate (in terms of failure number per year), r average failure duration or repair time (in unit of hours) and U not being ready (in unit of hours per year).

Table 1: Definition of reliability indices (Fotuhi-Firuzabad and Rajabi-Ghahnavie, 2005)

Definitions	Reliability Indices
System average interruption frequency index	*SAIFI*
Customer average interruption frequency index	*CAIFI*
System average interruption duration index	*SAIDI*
Customer average interruption duration index	*CAIDI*
Average service availability index	*ASAI*
Average energy not supplied	*AENS*

By determining the main parameters λ , r and U for each load points, it is possible to calculate the SAIFI and SAIDI and other indices considering the definition of Table 1 as follow.

$$SAIFI = \frac{\sum \lambda_i N_i}{\sum N_i}. \quad (1)$$

$$SAIDI = \frac{\sum U_i N_i}{\sum N_i}. \quad (2)$$

$$ENS = \sum L_a(i) \times U_i. \quad (3)$$

$$AENS = \frac{\sum L_a(i) \times N_i}{\sum N_i}. \quad (4)$$

Simple equations are considered for calculation of reliability regarding a certain failure rate and an average repair time for each part of distribution system. However, it has to be noticed that the reliability of system is not too simple and some factors can affect it like weather condition and phenomena, common failures, different outputs, cutting out a customer in some part, possibility of supplying loads from different feeders and effects of DGs.

In this paper, analytical method is used to calculate the reliability indices. This method is based on Failure Modes and Effect Analysis (FMEA). As the aim of this paper is to improve the reliability indices and to reduce the cut out number and duration due to voltage drop, failure modes are defined based on the short-circuit occurrence in buses and transmission lines which leads to voltage drop. Besides, availability or lack of it in load supplying is determined based on the sensitivity of consumer devices (load point) with respect to voltage drop and reliability indices in each load points are calculated based on load flow and short-circuit studies related to each failure mode. In fact, the main core is to solve the load flow program in presence of DG resources. As a result, forward and backward load flow is used in this paper.

Placement problem is an example of non-linear optimization. In this problem the place of DG resources and size of energy generation resources are considered as optimization variables. Load flow program is executed in each mode in order to investigate the reliability indices and fulfilling the technical and electrical constraints.

3.2. combinatorial objective function

In this paper, combinatorial objective function of optimization is consisted of three important reliability indices with identical share according to equation (5).

$$Objective\ Function = \frac{1}{3} \times SAIDI + \frac{1}{3} \times SAIFI + \frac{1}{3} \times AENS. \quad (5)$$

The aim of this problem is to minimize these reliability indices. Constraints of the problem consist of three parts, first part is related to DG resources which is about limitation of active and reactive power of resources. Second part is the limitation of rated voltage on the loads of network in a way in times of failures, voltage of buses would not reach to allowable limitations. These constraints are formulated as follows:

$$P_{DG_{min}} \le P_{DG_i} \le P_{DG_{max}}. \quad (6)$$

$$Q_{DG_{min}} \le Q_{DG_i} \le Q_{DG_{max}}. \quad (7)$$

$$V_{i_{min}} \le V_i \le V_{i_{max}}. \quad (8)$$

And the last part is related to the number of DG resources and candid places for placement.

4. Description of Global Confirming Particle Swarm Optimization (GCPSO)

Particle swarm optimization (PSO) was first presented by Kennedy and Eberhart in 1995[13]. This method is based on the results of simulation on social behaviors of things that live in group. In this algorithm, movement of each element is in the direction of speed vector that are updated in each stage by considering the best experience and its neighbors' best experience. Therefore, experiencing more optimal locations are possible in search space of the problem [13].

In most optimization problems, the range of global optimum is not clear. If the estimation of global optimal range is not carried out correctly, PSO algorithm would trap into local optimal points and would not reach to global optimal points. In this section, mutation and cross-over operators of GA are used in order to change the movement rules when it is close to local optimal points. Using these operators leads to better exchange of data between the elements of the groups and solution space is wider to find the global optimal point while convergence speed is remained unchanged. Hence, these operators have increased the performance of PSO algorithm in evading from local optimal points. Results show that when global optimal range is not clear, using combinatorial suggested algorithm has better performance comparing to ordinal PSO in finding global optimal point [14,15].

4.1. improving the PSO algorithm by cross-over and mutation operators

If all element of PSO algorithm are considered as neighbor of one element, the best element of group would always guide (lead) the other elements. Considering the movement rule of algorithm and $x_i = x_{pbest_i} = x_{gbest}$ for the best element of the group, it is understood that this element in the group has no leader and it only moves based on the variations of its speed vector. In other words, the following relation is always true for the leader element of the group:

$$v_i(t+1) = \omega \vec{v}_i(t) + c_1 r_1 \overbrace{\left(\vec{x}_{pbest_i} - \vec{x}_i(t)\right)}^{=0} + c_2 r_2 \overbrace{\left(\vec{x}_{gbest} - \vec{x}_i(t)\right)}^{=0} = \omega \vec{v}_i(t) \quad (9)$$

Therefore, if a better optimum is not found after some iterations, movement of the best element in the group is fixed and it is possible that all elements are converged toward the local optimal point based on movement rules. As a result, any solution that can amplify movement and search in search space would be paid attention. In this section, performance of PSO algorithm is improved by GA operators (cross-over and mutation). In the proposed method, data between two particles are improved by cross-over operator and mutation operator is used to evade from local optimum. In each iteration, two accidental particles are chosen as parents and cross-over operator (convex linear combination) is applied to them to add one particle to the group and after that, a percentage of particles are thrown to accidental points by mutation operator to be replaced by previous x_{gbest} if better points are found. It is noted that because particle have memory, applying these operators to the algorithm would not change the convergence speed of PSO. If more optimal points are found by applying these operators, particle move toward that point. If no optimal point is found by applying these operators, movement would not diverge because the particles have memory and hence convergence speed is kept the same. In this paper, the following equation is used to apply mutation operator on the particles (Michalewicz, 1992).

$$\Delta x = (var_{hi} - x_i)\left(1 - rand^{\left(1-\left(\frac{t}{t_{max}}\right)\right)^5}\right) - (x_i - var_{lo})\left(1 - rand^{\left(1-\left(\frac{t}{t_{max}}\right)\right)^5}\right) \quad (10)$$

where in above equations we have:

Δx: variation of location for elements that are mutated

var_{hi}: maximum value of variable x

var_{lo}: minimum value of variable x

$rand$: accidental number with uniform distribution in range (0,1)

t: iteration (counter of algorithm loop)

t_{max}: maximum value of algorithm loop iteration

The mutation cause some elements be out of determined range for search. Hence, points out of search space are searched accidentally.

4.2. Implementing the proposed algorithm

Optimal size and place of DG resources are determined by Global Confirming Particle Swarm Optimization algorithm with the aim of minimizing combinatorial reliability indices considering technical and electrical constraints as follow.

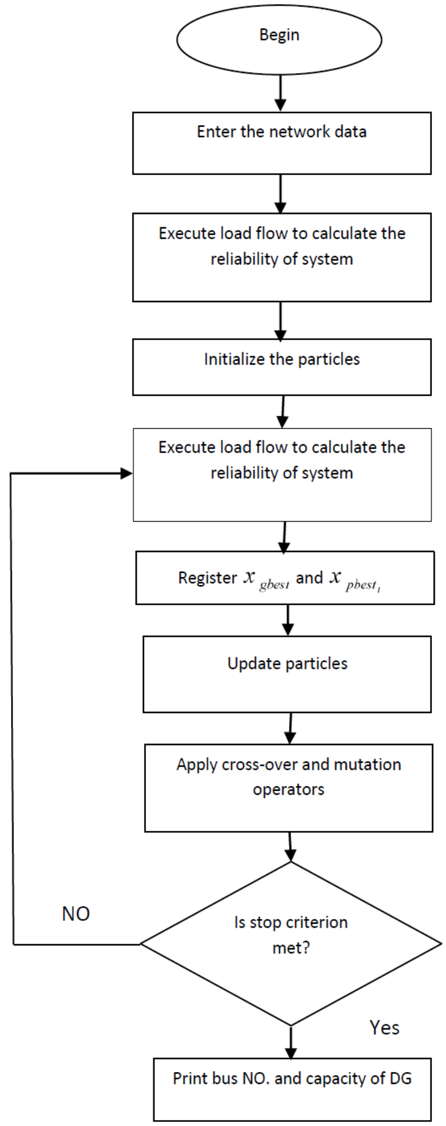

Fig 1: Flowchart of implementing the proposed algorithm on test network

5. SIMULATION AND RESULTS

5.1. under study system for implementing the proposed method

In this paper, a standard 33-bus modified IEEE test network is utilized for simulation, observation and results comparison (Fig 2.). Network data consists of lines data, loads, and average failure rate (short circuit) (Hosseini et al., 2008). Failure rate and repair duration are considered identical in line length unit.

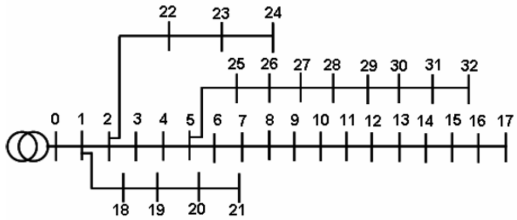

Fig. 2: Standard 33-bus modified IEEE network (Hosseini et al., 2008)

Network information is given in Table 2 in terms of reliability indices before installing any DG resources.

Table 2: reliability indices of network

AENS	SAIDI	SAIFI
4247.3 (*kWh/cust.year*)	3.0657 (*h/cust.year*)	1.5328 (*f/cust.year*)

5.2. description of different scenarios for placement of DG resources in 33-bus network

DG resources are considered as 1 MW and 2 MW units and it is assumed that we are able to connect 4 DG resources to the grid. Hence, 14 different scenarios would be considered according to Table 4 as an approach for placement of DG resources in order to improve the reliability indices by proposed algorithm.

In Global Confirming Particle Swarm Optimization algorithm, selection of parameters can extremely affect performance of algorithm like other intelligent algorithms. Hence, after iterative calculations and accurate selection of these parameters, the desired values according to Table 3 have achieved (Dryabary et al., 2010)[8]:

Table 3: Parameters of Global Confirming Particle Swarm Optimization algorithm

Number Of Particles	Number of Iterations	c_1	c_2	ω
150	30	1.4962	1.4962	0.7298

5.2.1. results obtained by placement of DG resources in 14 scenarios by Global Confirming Particle Swarm Optimization algorithm

Regarding the obtained results, it is concluded that the algorithm can solve the placement problem in all networks and have optimal and agreeable results in each scenario.

Table 4 shows results of placement of DG resources in 14 considered scenarios. In order to validate and perform a comparison, Figures (3) to (6) show the value of combinatorial objective function, reliability indices and calculated profit of system obtained by these placements in two PSO and GCPSO methods. It is shown that in each scenario combinatorial objective function and reliability indices have decreased considerably and superiority of the proposed method is prominent.

As shown in Figures, by increase in the number of DG resources, variation and improvement in above mentioned indices are negligible.

Table 4: scenario characteristics and the results

Scenario NO.	NO.of DGs	Capacity of DG				Bus number of DGs
		DG1	DG2	DG3	DG4	
1	1	1	-	-	-	6
2	1	2	-	-	-	6
3	2	1	1	-	-	4, 6
4	2	2	2	-	-	4, 6
5	2	2	1	-	-	4, 6
6	3	1	1	1	-	6, 4, 8
7	3	2	1	1	-	4, 8, 6
8	3	2	2	1	-	8, 4, 6
9	3	2	2	2	-	8, 4, 6
10	4	1	1	1	1	4, 6, 8, 23
11	4	1	1	1	2	6, 8, 24, 4
12	4	1	1	2	2	24, 6, 8, 4
13	4	1	2	2	2	8, 24, 4, 6
14	4	2	2	2	2	24, 4, 6, 8

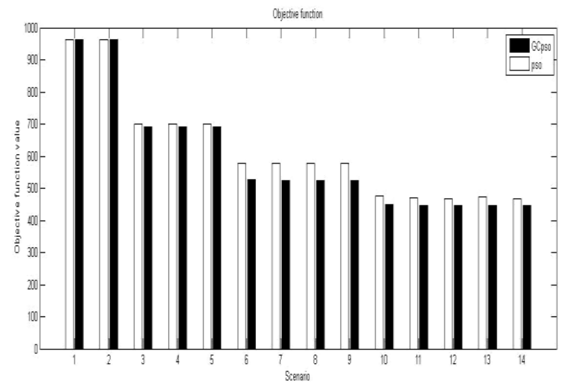

Fig. 3: objective function

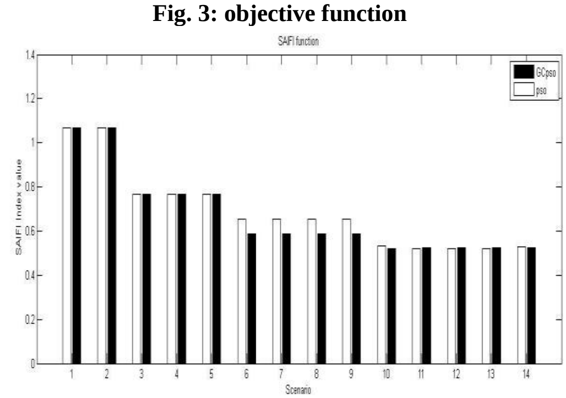

Fig. 4: average function of system cutoff frequency

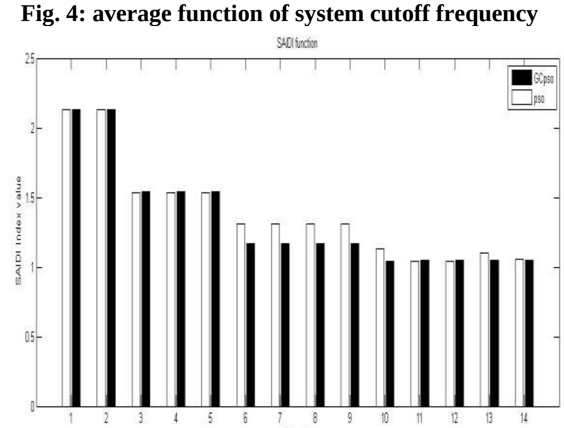

Fig. 5: average function of system cutoff duration

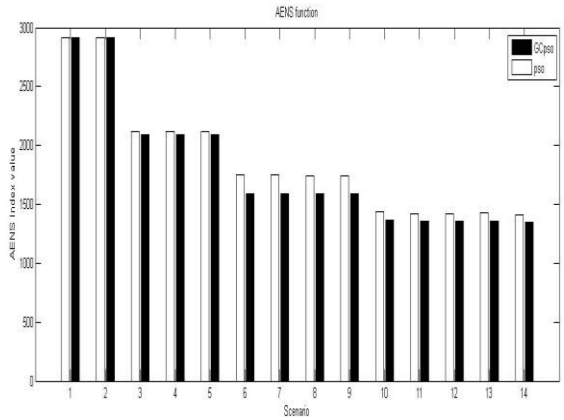

Fig. 6: unsupplied energy function

As shown in the Figures, it is concluded that adding generation units to the system have positive effect on reliability indices of system. However, it has to be noted that increase in the capacity of DG units causes a reduction in improvement of reliability.

6. CONCLUSION AND SUGGESTIONS

Utilizing DG units in distribution networks can have good advantages in reducing cut outs and improving reliability of distribution systems. If DG plants are connected to the grid, they will have different influences on the grid such as loss reduction, voltage profile improvement, reliability increase of the network. Improper placement of DG plants in the grid leads to increase in loss, over voltage of main feeder and increase in generation and transmission costs. Therefore, it is necessary to optimally place such plants by optimization methods. To do this, number of DG plants, place and size of installation have to be determined in a way maximum reduction of objective function is met considering constraints of the problem. In this research, objective function is presented based on the reduction of reliability indices. Calculation of objective function is by analytical method and considering the limitations of DG resources. Combinatorial objective function, reliability indices, optimal number and capacity of DG resources are determined by utilizing the proposed algorithm on a standard 33-bus modified IEEE test system. Simulation results show efficient influence of different parameters in presence or lack of DG resources, place of DGs, capacity of DGs and number of DGs in solving the problem. Besides, it is shown that the proposed algorithm have improved results comparing to ordinal PSO algorithm while convergence speed is remained unchanged. It is hoped to investigate the effects of simultaneous production of electricity and heat systems as a multi-purpose objective function in future works.

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