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Optimum Placement And Sizing Of Dgs Using Optimization Techniques And Distribution System Reconfiguration

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Abstract

This paper presents Distributed Generator (DG) sizing and placement problem and reconfiguration of distribution system using optimization techniques. For the DGs sizing and placement problem, the main procedures are identified, studied and analyzed. Works of different authors are reviewed to gain the basic knowledge of the problems. In the paper, the advantages of DG implementation are observed. Here the loss reduction of the distribution system is taken as the main objective function. To find the optimal result of this objective function, differential evolution (DE) and particle swarm optimization with extermal optimization (PSO-EO) techniques are used. In the second work, reconfiguration of the distribution system is executed by changing the statuses of sectionalize and tie switches of the system. Using differential evolution (DE) optimization technique, different switching combinations are created. Here the main objective is to minimize the loss of the system and find the best configuration of the radial distribution system.

Keywords

Distributed Generators, Genetic algorithms, Real Power Loss Reduction, Particle swarm optimization.

1. Introduction

Distribution companies require better planning strategies for meeting the forecasted load demand and to supply reliable power to the consumers. In the environment of deregulation scenarios, the traditional expansion of generations and transmissions systems to meet the load growth demand may not be economical and utilities need alternative technologies such as DGs implementation. Also with increasing concern of pollution and global warming, the current trend of power generation is switching towards the integration of renewable in the electrical power system. These renewable energy generations are solar photo voltaic generation, wind farm, fuel cell, biomass energy etc. These kinds of generations are placed in the different regions of the distribution system with the aim to reduce the transmission line loss, support the distribution system voltage and improve the reliability of the power system. Hence, these types of generations are termed as Distributed Generations (DGs), Dispersed Generations, Embedded Generations and Distributed Energy Resources (DERs) [1, 2].

DGs sizing and placement without any proper procedure can lead to increment of power loss in the system and exceed bus voltages beyond their limiting values [3-5]. The DGs sizing and placement problem can be solved by using optimization methods. In general, the formulation of an optimization technique is influenced by the behaviour of the living organism and such optimization techniques are genetic algorithms (GAs), gravitational search (GS), differential evolution (DE), particle swarm optimization (PSO), ant colony optimization (ACO) etc. These optimization techniques can be used to solve the research problem if it is formulated in form of a function [6]. A standard function is written in $y = f(x)$ form. Here for a certain value of x (decisive variables) the optimal value of y can be found out. This function can be linear or non-linear. The decisive or independent variables x can be single or multidimensional and mixed integer type. The search space of the decisive variables can be convex or non-convex in nature. Here to solve the function the optimization techniques can be utilized.

In radial distribution system, the power feeds from the substation. Transmitting power to a bus or node away from substation causes increment of power loss and reduction of bus voltage. DGs placed at different parts of this kind of distribution system, inject active and reactive power. These generating sources can improve voltages of the nearby buses. Due to these sources, the need of power from the substation decreases and hence the power loss in the system decreases. Some of DGs sizing and placement procedure using optimization techniques are discussed in next paragraph.

Using advance version of DE and PSO the DGs sizing and placement problems are solved by S. Kumar et. al. [7, 8]. M. P. Lalitha et. al. have analyzed these considering the active power of DG injection using PSO [9]. N. Mohandas et. al. [10] have shown the voltage stability based DGs allocation using advance artificial bee colony optimization. A. M. El-Zonkoly [11] has proposed load modeling based DGs placement using PSO. B. Mohan et. al. [12] have studied and implemented the market based DGs placement using genetic algorithm.

2. Problem Formulation of DG Placement Considering One After Another DGs Position Using Optimization Techniques

For a standard distribution system, the load flow equations are solved using Newton Raphson (NR) method for base case. The formulation of load flow is as follow:

$$f = P_{La} = \sum_{i=1}^{n} I_{ai}^2 R_i \tag{1}$$

$$P_i = \sum_j |V_i| |V_j| |V_{ij}| \cos(\theta_{ij} + \delta_j - \delta_i) \tag{2}$$

$$Q_i = -\sum_j |V_i| |V_j| |V_{ij}| \sin(\theta_{ij} + \delta_j - \delta_i) \tag{3}$$

$$V_{min} \leq |V_i| \leq V_{max} \tag{4}$$

$$MVA_{min} \leq MVA_{ij} \leq MVA_{max} \tag{5}$$

In Equations (1) the f or P_{La} is the active power loss due to the active component of current (I_{ai}) flowing in the system. The equality constraints to solve this power flow equation are given in equations (2, 3). P_i and Q_i are the active and reactive power injections for any ith bus respectively. $|V_i|$, δ_i are the ith bus voltage magnitude and angle, and $|Y_{ij}|$, θ_{ij} are the magnitude and angle of i-j line admittance respectively. Equations (4, 5) are the inequality constraints. MVA_{ij} is the value of apparent power flow through i-j line. V_{min} and V_{max} which are lower and upper limits of bus voltages, are chosen as .95 and 1.05 p.u, respectively.

2.1) Algorithm for DG Sizing and Placement

Step 1) Find the loss using equation (1) (loss due to active component of current) in the system with base case.

Step 2) Find suitable DG size and position using DE and PSO-EO optimization algorithms and find loss saving, DG injected current and DG size using equations (6), (7) and (8) respectively [9].

$$S = -\sum_{i=1}^{n} (2D_i I_{ai} I_{DG} + D_{DG} I_{DG}^2) R_i \tag{6}$$

$$I_{DG} = -\frac{\sum_{i\varepsilon\alpha} I_{ai} R_i}{\sum_{i\varepsilon\alpha} R_i} \tag{7}$$

$$P_{DG} = V_m I_{DG} \tag{8}$$

Step 3) When one DG size and position are achieved then the next DG position and size are found out considering the previous DG placed in its position.

Step 4) Repeat the procedure from step (2) until less than 1 kW loss saving (S) is achieved.

Step 5) Print the result.

2.2) Steps of Extermal Optimization (EO) of PSO

For improved result using PSO, an extra operation can be included for DGs placement problem. The extremal search for PSO introduces mutation of the decisive variables in certain iterations [13, 14].

Step 1: INV is counter for the EO operation. When$\{\mathrm{mod}(\mathrm{iter}, \mathrm{INV}) = 0\}$, the EO operation can be introduced in the PSO iteration(iter).

Step 2: In the DGs sizing and placement problem, the decisive variables are the bus numbers, which are natural numbers. The Gaussian distribution of these numbers can be achieved (9). x_i' is Gaussian mutated value of x_i and a_i and b_i are the lower and upper limits of the variables. σ_i is standard deviation of the variables. Using equations (10-14) the new mutated values of the decisive variables can be assigned. Value of α in the process is taken as $\frac{8(\pi-3)}{3\pi(4-\pi)} \approx 0.140012$.

Step 3: The objective function of active power loss calculation using equation (1) and the loss saving calculation equations (6-8) are computed for the population of mutated decisive variables of DG position.

Step 4: A mutated decisive variable of DG position can only replace an original decisive variable if it gives improved value of objective function. Otherwise, there will be no change.

$$p(x_i'; x_i, \sigma_i) = \begin{cases} \dfrac{\frac{1}{\sigma_i}\emptyset\frac{x_i' - x_i}{\sigma_i}}{\emptyset\frac{b_i - x_i}{\sigma_i} - \emptyset\frac{a_i - x_i}{\sigma_i}}, \text{if } a_i \le x_i' \le b_i \\ 0 \qquad\qquad\qquad\qquad , \text{otherwise} \end{cases} \tag{9}$$

$$x_i' = x_i + \sqrt{2}\sigma(b_i - a_i)\mathrm{erf}^{-1}(u_i') \tag{10}$$

$$u_i' = \begin{cases} 2u_L(1 - 2u_i), \text{if } u_i \le 0.5 \\ 2u_R(2u_i - 1), \text{otherwise} \end{cases} \tag{11}$$

$$\mathrm{erf}^{-1}(u_i') \approx \mathrm{sign}(u_i')\left(\sqrt{\left(\frac{2}{\pi\alpha} + \frac{\ln\left(1 - {u_i'}^2\right)}{2}\right)^2 - \frac{\ln\left(1 - {u_i'}^2\right)}{2}} - \left(\frac{2}{\pi\alpha} + \frac{\ln\left(1 - {u_i'}^2\right)}{2}\right)\right)^{0.5} \tag{12}$$

$$u_L = 0.5\left(\mathrm{erf}\left(\frac{(a_i - x_i)}{\sqrt{2}(b_i - a_i)\sigma}\right) + 1\right)$$
$$u_R = 0.5\left(\mathrm{erf}\left(\frac{(b_i - x_i)}{\sqrt{2}(b_i - a_i)\sigma}\right) + 1\right) \tag{13}$$

$$\mathrm{erf} = \frac{2}{\sqrt{\pi}}\int_0^y \exp(-t^2)\,dt \tag{14}$$

This extremal optimization (EO) operation is conducted for some of the generation of PSO to guide the swarm to the global optimum value.

2.3) Results of DG Sizing and Placement

In this part of paper, the procedure of the problem is analyzed. For this paper, IEEE 33 bus distribution system data is used. IEEE 33 bus distribution system [15] has 33 buses and 32 lines. The base values are 12.66 kV and 100 MVA. The total load values are 3.715 MW and 2.300 MVAr. The original loss due to active component of current is 135. 9499 kW.

For IEEE 33 bus test system, the search space is single dimensional and bounded among bus numbers 2 to 33. For DE and PSO-EO algorithms, the bus number for DG placement is taken as target vector and particle value respectively. Individually using both algorithms in iterative process the optimal DG position and loss saving are found out. The parameters for DE, PSO-EO are shown in Table-1. After trial and error the INV value of PSO extremal optimization is chosen as 10 for this problem.

Table-1: Optimization Techniques DE and PSO-EO Parameters for Algorithms

Parameters	DE	Parameters	PSO-EO
Generation No. (G)	200	Iteration No. (G)	200
Population No. (N)	20	Population No. (P)	20
Mutation Factor (F)	0.6	Acceleration Constants (c1, c2)	1, 3
Cross-over Ratio (CR)	0.9	Initial and Final Weight (ω_{min} and ω_{max})	0.4, 0.5
		INV	10

As per the single DG sizing and placement problem described earlier, the DG is placed in the IEEE 33 bus distribution system and result of the procedure is enlisted in the Table-2a and Table-2b. In four runs when one after another DG placement is executed, the base loss 135. 9499 kW decreases for DE and PSO-EO algorithms. In Table 2a and Table 2b, the comparisons of DG placement are shown for three different procedures.

Table-2a: Comparison of the Result of DG Placement Considering DGs Placement

S. No.	DG Positions			Size (MW)		
	DE	PSO [9]	PSO_EO	DE	PSO [9]	PSO_EO
1	6	6	6	2.4875	2.4886	2.4875
2	15	15	16	0.4524	0.4406	0.4141
3	25	25	25	0.6717	0.6473	0.6529
4	32	32	33	0.2457	0.4345	0.2547

Table-2b: Comparison of the Result of DG Placement Considering DGs Placement

S. No.	Loss Reduction (kW)			Loss Value After DG Placement (kW)		
	DE	PSO [9]	PSO_EO	DE	PSO [9]	PSO_EO
1	92.0935	92.1751	92.0935	43.8564	44.8085	43.8564
2	10.4240	11.4385	10.8882	33.4324	33.3700	32.9573
3	7.9524	7.6936	7.9355	25.4800	25.6764	25.0218
4	0.0432	8.1415	2.8432	25.4368	17.5349	22.1786

In Table 2a, the DGs position and size for the system found by the three different processes are enlisted. Using advanced PSO-EO and DE, new and effective positions and sizes of DGs are achieved that can reduce the loss to much lower value. From Table 2b, it can be analyzed that in third run of the problem, the loss reductions are obtained as 7.9355 kW and 7.9524 kW using PSO-EO and DE respectively. These values are superior to the 7.6936 kW loss reduction obtained from [9].

3. Reconfiguration of Distribution System

Any distribution system comprises of sectionalize switches in between the connecting nodes and tie switches in tie bars which are usually not connected. The different statuses of the sectionalize switches and tie switches create different radial topologies for the distribution system. Here for a particular load setting, the optimal switching statuses with minimum loss can be found out for each distribution system. This kind of power system problem is termed as reconfiguration of the distribution system [15, 16].

Different authors have solved this problem using different methods and different optimization techniques. D. Pal et. al. [17] have solved this problem using differential evolution (DE). H. R. Esmaeilian et. al. [18] have solved the dual problem of reconfiguration of distribution system and capacitor placement considering load modeling. H. Ahmadi et. al. [19] have formulated this problem using mathematical modeling and graph theory approach. S. S. F. Souza et. al. [20] have introduced new artificial immune meta heuristic technique for the reconfiguration of distribution system. Wanlin Guan et. al. [21] have formulated this problem using different types of DG units. Tamer M. Khalil et. al. [22] have used looping and dimention concept while finding the optimal switching combination for the distribution system.

3.1) Problem Formulation of Reconfiguration of Distribution System

The problem of reconfiguration of distribution system is solved using differential evolution (DE). Here the IEEE 33 bus distribution system [15] and IEEE 69 bus distribution system [23] are taken to solve the reconfiguration problem. The IEEE 33 bus distribution system has 32 sectionalize switches and 5 tie switches (S33, S34, S35, S36, S37) and IEEE 69 bus distribution system consists of 68 sectionalize switches and 5 tie switches (S69, S70, S71. S72, S73). For individual distribution system, a set of sectionalize switches is assigned for each tie switch. This set of sectionalize switches are chosen as per the looping occures due to closing of each tie switch. The five loops for the each distribution system are shown using roman numerals in Fig. 1 and Fig. 2. As per looping some of the sectionalize switches can come under more than one tie switch. In this case, the overlapping switches are considered to opearte under any one randomly selected tie switch.

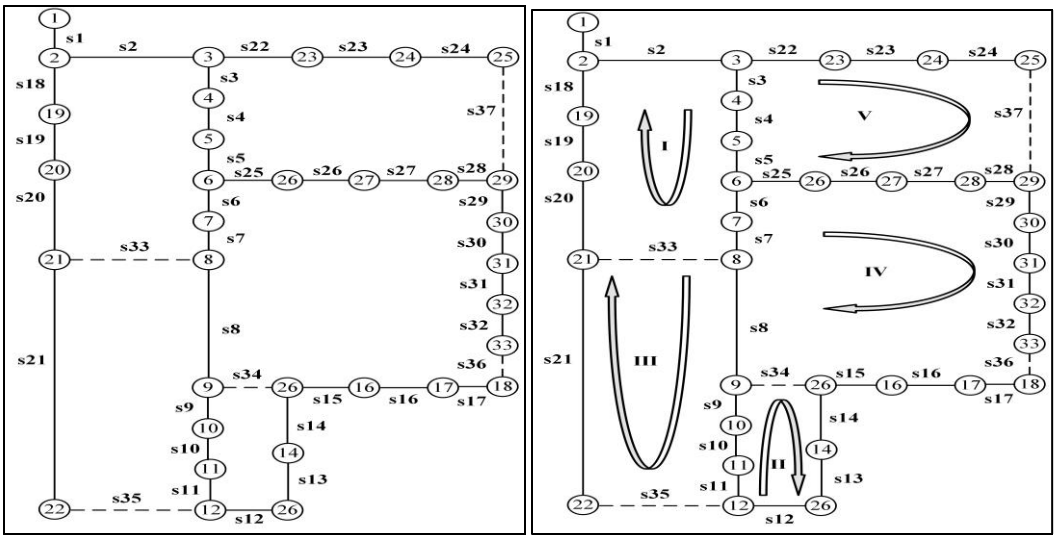

Fig.1: IEEE 33 Bus Distribution System and the Loops Created due to Closing of Tie Switches

While solving this problem using DE, the decisive variable is chosen among the sectionalize switches and closing of one tie switch leads the DE algorithm to find the optimal sectionalize switch which has to be opened. A set of sectionalize switches are assigned on a tie switch and manually closing of one tie switch, restricts the search space in that set of sectionalize switches. Closing more than one tie switch can increase the dimension of the problem and hence the boundary of the search space. The number of closed tie switches and open sectionalize switches should be same; otherwise there will be invalid switching configuration or islanding of the buses or nodes.

Using DE algorithm numerious configurations can be formed and for each configuration, the objective function of the power loss calculation can be computed using NR load flow method. Utilizing proper evolution and selection steps of DE, the optimal switching combinations of IEEE 33 and 69 bus distribution system are found out. DE parameters and the comparison of results coming from different methods are shown in Table 3 and Table 4 respectively.

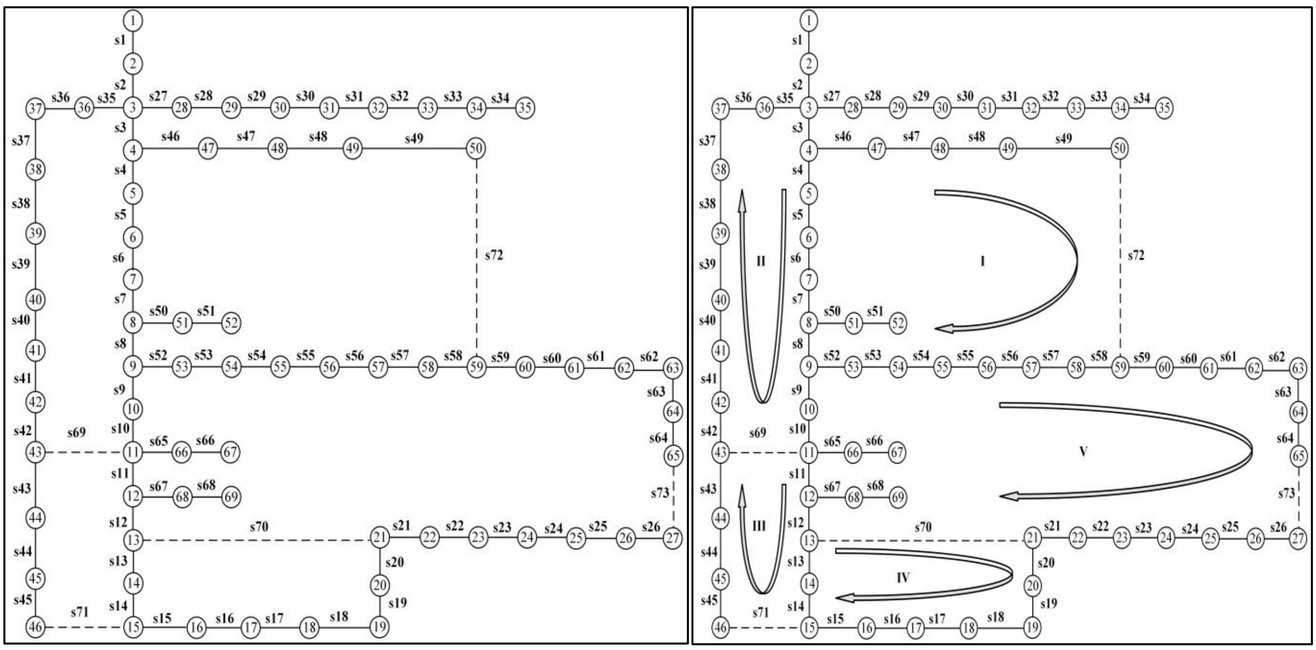

Fig.2: IEEE 69 Bus Distribution System and the Loops Created due to Closing of Tie Switches

3.2) Result of Reconfiguration of Distribution System Considering Dimension

As per the system data used in [15] and [23], the base active power loss is found out as 202.6 kW and 224.96 kW for IEEE 33 and 69 bus distribution system respectively. Using DE, the best configurations are obtained for both systems and the loss reduced to 139.5513 kW and 125.2257 kW respectively. The percentage of loss reduction and finding optimal configurations using DE establish the superiority of DE than the procedure used in [22]. The DE parameters for both systems are shown in Table 3. The result and the comparison of the methods are enlisted in Table 4.

Table-3: Optimization Techniques DE and PSO Parameters for algorithms

DE Parameters for IEEE 33 Bus Test System		DE Parameters for IEEE 69 Bus Test System	
Generation No. (G)	200	Generation No. (G)	400
Population No. (N)	20	Population No. (N)	40
Mutation Factor (F)	0.6	Mutation Factor (F)	0.6
Cross-over Ratio (CR)	0.9	Cross-over Ratio (CR)	0.9

Table-4: Comparison of the Result of Loss Reduction Using DE

Test System	Open Switch		Base Case Loss (kW)	After Loss Reduction (kW)	Percentage Loss Reduction
	Base Case	After Reconfiguration			
33[22]	S33, S34, S35, S36, S37	S7, S9, S14, S32, S37	202.6	139.7940	31
33	S33, S34, S35, S36, S37	S7, S14, S8, S16, S37	202.6	139.5513	31.1979
69[22]	S69, S70, S71. S72, S73	S69, S70, S14, S56, S68	224.96	125.9776	44
69	S69, S70, S71. S72, S73	S69, S70, S13, S58, S64	224.96	125.2257	44.3342

From Table 4., the precentage of loss reductions are obtained as 31.1979% and 44.3342% for IEEE 33 and 69 bus test system using DE. Due to the simple problem formulation using DE the more improved value of percentage loss reduction is obatined. The convergence characteristics in between the objective function of loss reduction and generation for both systems are shown in Fig. 3 and 4.

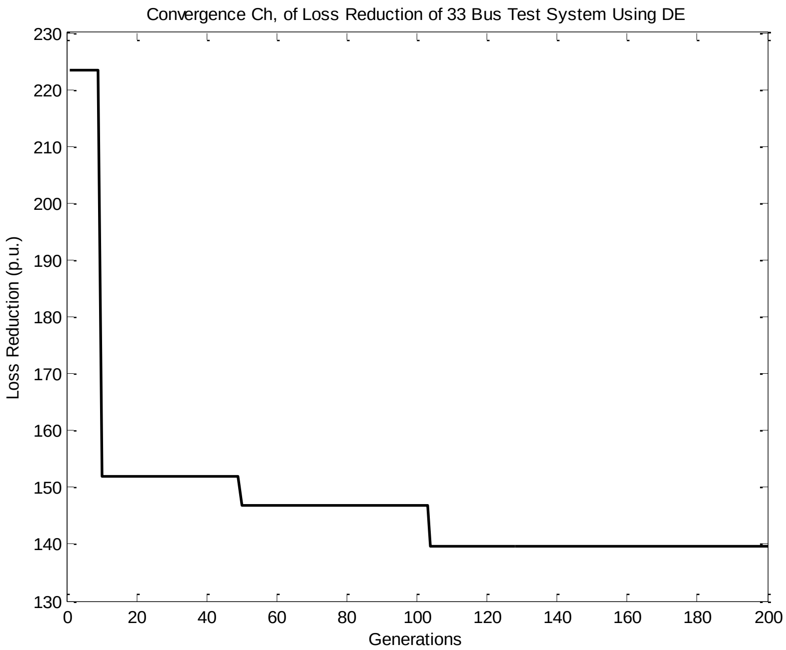

Fig- 3: Convergence Characteristic of Loss Reduction of IEEE 33 Bus Test System Using DE

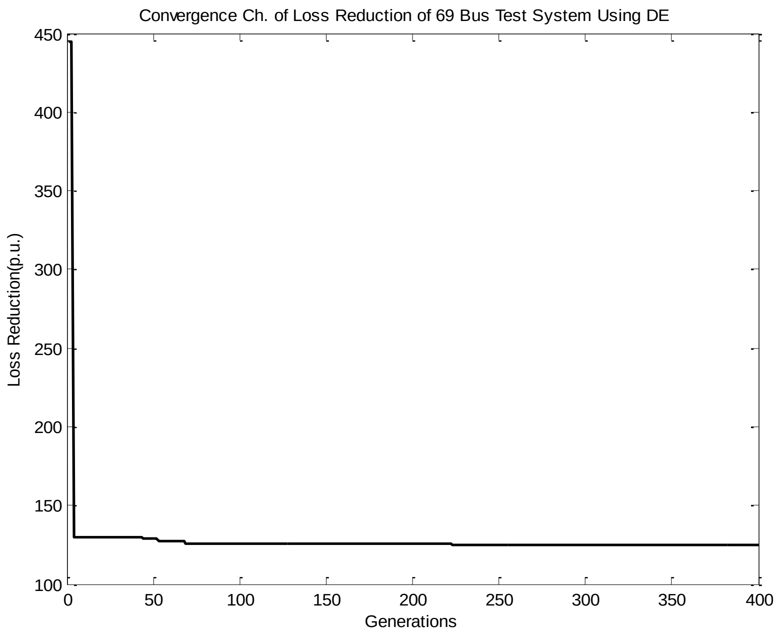

Fig- 4: Convergence Characteristic of Loss Reduction of IEEE 69 Bus Test System Using DE

After some trial, the generation number for IEEE 33 bus test system is taken as 200 and for much bigger system of IEEE 69 bus test system, that generation number is chosen as 400. From the convergence charactertics of loss reduction vs. generation number of IEEE 33 bus, it can be concluded that the plot takes more than 100 generations to settle down to a optimal value. IEEE 69 bus's convergence characteristics comes down from a higher value to much lower objective function value due efficient formulation of DE algorithm. In between 200th and 250th generation the optimized value of objective function of loss reduction is reached.

3.3) Reshuffling of "from" bus and "to" Bus

In the problem of reconfiguration, the line data for a bus is given. This base distribution system structure is radial or tree type and all sectionalize switches are closed. In the process of any optimization technique, depending on the clsoing and opening tie and sectionalize switches respectively, the structure of the distribution system changes, hence the path of unidirectional power flow changes. As the power flow path changes the "from" bus and "to" bus interchange their positions. This change should be reflected to the line data of the system. Otherwise, after this change and with this prefixed line data, load flow would give invalid or unacceptable results. To overcome the problem, the reshuffling of "from" bus and "to" bus data is executed.

3.4) Steps of Reshuffling of "from" Bus and "to" Bus

Step1: For a switching combination, the structure of the distribution system and the position of "from" bus and "to" bus are changed. To resuffle those buses or nodes, first endbuses or endnodes of this tree structure has to be found out. Each endnode appears only once in either "from" or "to" bus data.

Step2: Now starting from each endnode, the substation bus or node has to be found out using depth first search method. The depth first searching is operated in the "from" bus and "to" bus data and the in between buses or nodes have to be stored.

Step3: Again using backtracking and starting from substation bus or node, each endnode is found out from the previously stroed values and the inbetween buses or nodes are stored in form of new "from" bus and "to" bus. Here a set of "from" and "to" bus appears more than onec in the new assigned matrix. This problem has to be taken care of by taking each set only once.

Step 4: The others "from" and "to" bus related data, have to be rearranged once again.
Using these steps of resuffling of "from" bus and "to" bus, a valid switching combination of the distribution system never appeares as invalid switching combination and unidirectional power flow is maintained.

Conclusion

In this paper, DGs sizing and placement problem in distribution system and reconfiguration of distribution system are solved by implementation of optimization techniques. To solve DGs sizing and placement problem, IEEE 33 bus test system is choosen. DGs placement in this system using DE and PSO-EO give more improved result in term of loss reduction than previously applied classical PSO in the literature. In another part of the paper, the DE algorithm is used to find the optimized configuration of IEEE 33 and 69 bus test systems. The main objective of this part of the paper is to reduce the system loss using reconfiguration. Loss reductions for both system using DE produce gives more improved results than the classical PSO applied in the literature.

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