International Journal on Future Revolution in Computer Science & Communication Engineering ISSN: 2454-4248
Volume: 4 Issue: 3 41 – 48

Simultaneous Placement of Distributed Generation and Reconfiguration in Distribution Networks Using Unified Particle Swarm Optimization

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Abstract—The power distribution feeder reconfiguration and optimum placement of distributed generation are two main methods to minimize the active power loss in radial distribution systems. The robustness of the radial distribution system can be improved by simultaneous manipulation of both optimal DG placement and feeder reconfiguration. In this paper, a novel technique is proposed to minimize the power loss with the simultaneous use of feeder reconfiguration and placement of distributed generation. In general, an electrical power network economics primarily relies on the conductor line losses. Hence in this proposed study, the feeder reconfiguration and finding of desirable bus location and operating power of distributed generation is concurrently modeled as an optimization problem for minimizing the real power loss with subject to all operating equality and inequality constraints. This optimization problem is solved with the guide of unified particle swarm optimization algorithm. The system power loss is handled as the cost function for each particle in a swarm. The proposed method is applied to both IEEE 33-bus and IEEE 69-bus radial distribution systems. The prosperous solutions achieved from the simulation studies manifest that the high level of system loss reduction and desirable bus voltage profile, when analyzed against the system with reconfiguration, and the system with DG.

Keywords*-Distributed generation, Feeder reconfiguration, Particle swarm optimization, Radial distribution system, Real power loss, Unified particle swarm optimization*

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I. INTRODUCTION

Power loss minimization in the radial distribution systems is the most significant priority in the planning and operation of an electrical system. The power generated from the power station is dispersed to the various load consumers through transmission and distribution systems. The power generated from the power plants is not equal to the power consumed by the various load centres, this is due to fact that a few amount of energy loss can occur during the power transmission.

Substantial percentage of the produced energy from power plants is wasted from the production to consumption area. The most extreme rate of energy loss in an electric grid is due to transmission and distribution line losses. But the distribution systems cause a loss of about 5 to 13% of the power produced from the power plants [1]. The apparent power loss of an AC transmission and distribution line is expressed in complex form $I^2(R+jX)$. On account of substantial resistance (R) to reactance (X) ratio characteristics of the radial distribution system (RDS) [2], the primary component of the apparent power loss in an AC distribution line is real power loss. Since the resistance is a real portion of AC distribution line impedance, the resistive loss in an AC system equivalent to active power loss. The power line resistive loss reduction in an AC distribution system presumes an essential part in economic operation and planning of a complete power system. Typically, the loss minimization problem in an electrical power network is a very critical and more difficult task to solve. Thus the objective of the presented study is to reduce the real power loss of RDS [3, 4].

Distributed generation (DG) integration in power distribution network is experiencing speedy growth in lots of nations due to its availableness of various power sources like photovoltaic cells, fuel cells and wind energy conversation systems [5, 6]. DG is commonly integrated with a de-centralized fashion by the idea of micro-grid. A DG producing active power (power generating station equipped with the solar cell or hydrogen fuel cell) installed at situation node of a distribution system can reduce the active power loss by minimizing the current withdrawn from the sub-station [3]. In present days, the idea of integrating the active power delivering DGs in RDS has been increased in greater extent due to its smooth implementation and enhanced network performances [7-9].

Generally, distribution power systems are structured to be radial, to just have a single way between every load consumers and the substation. The radial networks have a few points of interest over meshed systems, including very low short circuit current and less difficult switching and ensuring machine protection. Nevertheless the radial design gives good overall reliability. Therefore, to utilize the advantages of the radial design and, in the meantime, to conquer the challenges, distribution frameworks are arranged and built as weakly meshed systems but operated in radial structure.

One way to manage the security, reliability and quality of the framework is by reconfiguring the RDS. The idea of integrating optimal feeder reconfiguration in RDS has been increased in greater extent due to its smooth implementation and enhanced network performances [10-12]. The modification of the system structure is finished by methods for changing the status of the open and close tie switches. Certain switches can be worked remotely regardless of the way that the others are opened or closed by a lineman. When planning system reconfiguration, the load profile of various users are conceived to see if a specific reconfiguration is reliable, secure, and has sufficient ability to supply every one of the end users. Once the feeder reconfiguration is carried out, overburdening of the feeder is decreased, I^2R power loss is reduced, and the voltage profile of the framework is enhanced, thereby prompting the voltage profile enhancement. Because

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of the fact that the active power loss of an electrical system is directly proportional to the real part of the line current, an optimal feeder reconfiguration can reduce the system loss.

For the past two decades, the loss minimization optimization problem of the power distribution systems have been solved with the application of artificial intelligence (AI) algorithms [13-16]. The optimum rating and placing of DGs in a distribution system with the aid of naturally propelled artificial algorithms turn out to be more energizing and popular vogues in the domain of radial distribution network optimization and enhancement [13, 14]. The location and rating of DGs have been obtained by using both Particle Swarm Optimization (PSO) and parameter improved PSO (PIPSO) techniques with real power loss as swarm fitness function and the minimization problem considers power balance constraint, DG generation limit and node voltage limit [14]. Besides, it has been proved that the optimum DG placement in RDS using PSO and PIPSO algorithms have better loss reduction and fast convergence properties. Some of the analysts have executed the use of AI methods to reduce the active power loss in RDS by incorporating optimal feeder reconfiguration [15, 16]. The active power loss minimization has been considered as the fitness function to reconfigure the large-scale RDS using improved Tabu Search Algorithm (TSA) [15]. Ant Colony Optimization (ACO) technique based radial network reconfiguration has been developed to minimize the system real power loss [16]. Furthermore numerous solution techniques namely Shuffled Frog Leap Algorithm (SFLA) [17], Modified Monkey Search Algorithm (MMSA) [18], Whale Optimization Algorithm (WOA) [19], Shark Smell Optimization (SSO) [20], Hybrid PSO with Quasi Newton Algorithm [21], Improved Harmony Algorithm (IHA) [22], Cuckoo Search Algorithm (CSA) [23], combined Harmony Search and Artificial Bee Colony Algorithm [24], PSO combined with Eagle strategy [25] and analytical approach [26] have been developed for solving loss minimization problem in RDS.

The particle swarm optimization algorithm has pulled many investigators' sights due to its effectuality and simplicity. PSO algorithm animated from the bird flocking and fish schooling, is a flexible, robust, population based optimization technique that is been implemented by many researchers to solve the engineering problems as well as various power system problems. Numerous advantages and usefulness of the PSO algorithm can be seen in many research studies when solving the engineering optimization problems [27-29].

Unified Particle Swarm Optimization (UPSO) is a special meliorated of PSO technique that can control the local and global parameters of standard PSO algorithm by combining its exploration and exploitation properties without enforcing any additional requirements in terms of fitness computations. Preliminary studies have shown that UPSO can tackle efficiently different optimization problems [30, 31]. The performance of UPSO has been first analysed on four different engineering constrained optimization problems with the fitness function similar to the power loss function of the electrical power distribution system. The framework which has been analysed with UPSO is implemented in the design of a tension/compression spring, design of a welded beam, design of a gear train, and design of a pressure vessel [31].

Hence in this paper, by considering the advantages of the optimal feeder reconfiguration, optimal placement of DG in distribution systems and the application of intelligent PSO technique in engineering optimization, an extended version of PSO algorithm called unified particle swarm optimization is employed to minimize the power loss with the simultaneous use of feeder reconfiguration and placement of DG in IEEE 33-bus and IEEE 69-bus power distribution systems. UPSO is a particular version of PSO algorithm that controls the local and global parameters of PSO by compounding their discovery and development skills without enforcing extra duties when computing fitness functions. The proposed UPSO technique based feeder reconfiguration and DG placement for real power loss minimization problem in power distribution system is formulated and the obtained results are compared against the system with reconfiguration alone as well as the system with DG alone, providing useful conclusions considering the effectiveness and proficiency of the proposed unified method.

After the introduction, a brief description of the power loss optimization problem colligated with its mathematical formulation is presented in Section 2, while in the Section 3 explains the standard PSO, proposed UPSO, and its algorithmic steps to find the optimal feeder reconfiguration and DG placement in RDS. Simulation studies are presented in Section 4. Finally, the conclusion is drawn in Section 5.

II. PROBLEM FORMULATION

It is showed that the simultaneous placement of the optimum DG at the desirable node and feeder reconfiguration can adequately decrease the active power loss of a radial distribution network [32]. Thus the objective of the presented work is gestated as active power loss minimization of distribution system, whose exact active power loss P_L equation is represented as [33],

$$Minimize\,P_L = \sum_{i=1}^{n}\sum_{j=1}^{n}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)\right] \quad (1)$$

where,

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos\left(\delta_i - \delta_j\right) \quad (2)$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin\left(\delta_i - \delta_j\right) \quad (3)$$

$$Z_{ij} = r_{ij} + jx_{ij} \quad (4)$$

where r_{ij} & x_{ij} is the resistance and reactance of the power line connecting nodes i & j respectively; Z_{ij} is the impendence of the power line connectingnodes i & j; V_i & δ_i is the bus voltage magnitude & angle at node i respectively; V_j & δ_j is the bus voltage magnitude & angle at node j respectively; P_i and Q_i the real & reactive power injected at node i respectively; P_j & Q= is the real and reactive power injected at node j respectively; n is the number of nodes in the system.

A. Subjected to constraints

- Real and reactive power balance

$$P_{Gi} - P_{Di} = \sum_{j=1}^{n} V_i V_j \left[G_{ij} \cos(\delta_i - \delta_j) + B_{ij} \sin(\delta_i - \delta_j) \right] \quad (5)$$

$$Q_{Gi} - Q_{Di} = \sum_{j=1}^{n} V_i V_j \left[G_{ij} \sin(\delta_i - \delta_j) - B_{ij} \cos(\delta_i - \delta_j) \right] \quad (6)$$

where P_{Gi} & Q_{Gi} is real & reactive power generated by DG at node i respectively; P_{Di} & Q_{Di} is real & reactive power demand at node i respectively; G_{ij} & B_{ij} is the conductance & susceptance of the power line connecting nodes i & j respectively.

- DG power generation limits

$$P_{Gk\min} \le P_{Gk} \le P_{Gk\max} \quad (7)$$

where P_{Gkmin} & P_{Gkmax} is minimum & maximum power production limits of DG k respectively.

- Bus voltage limits

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

where V_{imin} & V_{imax} is minimum & maximum voltage limits of bus i respectively.

III. PROPOSED METHODOLOGY

In this paper, we proposed an UPSO algorithm to find out the optimal reconfiguration and optimal DG placement in RDS by minimizing the power loss of the network.

A novel technique has been confronted in this section to find the optimal feeder reconfiguration and desirable DGs in RDS. This method expends the invention of naturally invigorated optimization algorithm called UPSO for real loss reduction in the radial power system by discovering the best feeder reconfiguration, appropriate bus location and operating power of DGs. In addition to UPSO technique, a backward-forward sweep power flow algorithm has been utilized to estimate the line flows and bus voltage of the radial power system coordinated with DGs [34]. The conception and algorithmic steps of the proposed UPSO for active power loss reduction in radial power distribution network equipped with optimal feeder reconfiguration and DGs is exemplified in the successive sections.

A. Unified particle swarm optimization algorithm (UPSO)

PSO technique is fundamentally admonished from the behavioral attributes of natural drift developed individual in bird flocking or fish schooling. In 1995, the thought of PSO technique to resolve the engineering problem was developed by Eberhart and Kennedy [27].

PSO strategy examines for worldwide best solutions in an engineering optimization problem by cooperating with the particle in a swarm. Each particle in a population has prominent properties of particle position and velocity. Hypothetically in an optimization problem, the particle's position *'x'* and velocity *'v'* is symbolized as working solution and step length for successive iterations respectively.

For an optimization problem with 'N' decision variables, let *'m'* be the particle's population size, then the i^{th} particle's position and velocity can be signified as $x_i = [x_{i1}, x_{i2}, \ldots, x_{iN}]$ and $v_i = [v_{i1}, v_{i2}, \ldots, v_{iN}]$ respectively. For every iteration, the position of i^{th} particle is examined against its earlier optimal position. If the current position is better than the earlier optimum one, then it is officially appointed as the optimal local position for the corresponding particle, and it can be signified as $p_i = [p_{i1}, p_{i2}, \ldots, p_{iN}]$. The overall optimal solution between all individuals in a swarm is perceived as the optimal global solution with position vector $p_g = [p_{g1}, p_{g2}, \ldots, p_{gN}]$. The i^{th} particle's position and velocity for the successive iterations are modified by utilizing its present velocity and its step length between the optimal global position, and the optimal local position, the formula to amend the new position and velocity of the i^{th} particle can be expressed as,

$$v_{id}^{t+1} = \omega . v_{id}^{t} + \varphi_1 (p_{gd} - x_{id}^{t}) + \varphi_2 (p_{id} - x_{id}^{t}) \quad (9)$$

$$x_{id}^{t+1} = x_{id}^{t} + v_{id}^{t+1} \quad (10)$$

where ω is inertia weight; d is variable index; $\varphi_1 = c_1 r_1$ & $\varphi_2 = c_2 r_2$; c_1 & c_2 are two positive acceleration coefficients called social and cognitive agents respectively; both r_1 & r_2 are uniform distribution random variables on the interval [0, 1]; t is the iteration count.

By extending the degree and idea of PSO technique, UPSO technique was first figured by Parsopoulos and Vrahatis [30, 31], is an extraordinary variant of PSO technique that controls the local and global parameters of PSO by aggravating their revelation and improvement powers without upholding additional obligations when processing the fitness functions. This updated version of UPSO procedure can better both the local and global positions towards the end of the iteration. Accordingly the proposed method requires less number of iterations to accomplish the global best solution for any kind of engineering problems. The two parameters are utilized in UPSO technique to accomplish both the advantages of global and local particle's position updates. These two parameters can be formulated as,

$$G_{id}^{t+1} = \chi (v_{id}^{t} + \varphi_1 (p_{gd} - x_{id}^{t}) + \varphi_2 (p_{id} - x_{id}^{t})) \quad (11)$$

$$L_{id}^{t+1} = \chi (v_{id}^{t} + \varphi_1^{'} (p_{hd} - x_{id}^{t}) + \varphi_2^{'} (p_{id} - x_{id}^{t})) \quad (12)$$

where, G^{t+1}_{id} & L^{t+1}_{id} represents the global and local parameter of particle's velocity update for particle i respectively; $\varphi'_1 = c_3 r_3$ & $\varphi'_2 = c_4 r_4$; where c_3 & c_4 are two positive acceleration coefficients, r_3 & r_4 both are uniform distribution random variables on the interval [0, 1]; d is the dimension of the problem.

The two explore steps Eq. (11) and Eq. (12) are thus aggregated into a single form as,

$$V_{id}^{t+1} = r G_{id}^{t+1} + (1 - r) L_{id}^{t+1} \quad (13)$$

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$$x_{id}^{t+1} = x_{id}^{t} + V_{id}^{t+1} \quad (14)$$

where, r is uniform distribution random variable on the interval [0, 1], which adverted to unification factor that identifies the shapes of both local and global explore steps. Evidently, $r = 0$ and $r = 1$ corresponds to local and global parameters of PSO algorithm. The aim of the presented paper is the desirable bus location and operating power of DG in RDS with the aid of UPSO. The implementation of the proposed method is described in the following section.

B. Algorithmic procedure

The algorithmic steps to discover the optimal feeder reconfiguration, desirable bus location and operating power rating of DGs in RDS are discussed in this section.

Let *'m'* be the population size and *'N'* be the number of decision variables in an optimization problem. For optimal feeder reconfiguration, DG placement and sizing problem, the number of open switch in a radial system is *'n1'*, the number of DGs to be installed in a radial system is *'n2/2'*; such that, a set of *'n2/2'* variables to find optimal DG location and another set of *'n2/2'* variables to calculate the optimal DG operating power. Thus, the total number of variables in a particle is $N = n1 + n2$.

Step 1: Read RDS's load and line data.

Step 2: Select reasonable esteems for UPSO coefficients and set iteration index as $t = 1$.

Step 3: Arbitrarily arrange workable solution for all *'m'* particles in vector *form* $x_i = [x_{i1}, x_{i2},... x_{in1}, x_{in1+1},...., x_{in2/2}, x_{in2+1/2},.... x_{in2},]$, $i = 1$ to m; where x_{i1} to x_{in1} denotes the open switch position of feeder lines on the interim [2, nbus]; x_{in1+1} to $x_{in2/2}$ represents DG location on the interval [2, nbus]; $x_{in2/2+1}$ to x_{in2} represents DG size on the interval $[P_{Gkmin}, P_{Gkmax}]$.

Step 4: For particle i, open the tie switch positions (x_{i1} to x_{in1}) in the power distribution system, consider DG (x_{in1+1} to $x_{in2/2}$) as negative load and locate at the bus ($x_{in2/2+1}$ to x_{in2}).

Step 5: For particle i, execute backward/forward sweep power flow algorithm on radial distribution with DG to estimate line flows, node voltage and active power loss using Eq. (1). Specify the estimated active power loss as fitness value to i^{th} particle. Again go to step 4 for all remaining particles.

Step 6: Find the local optimum position p_i for i^{th} particle and the global optimum position p_g among all particles on the basis of the minimal cost function.

Step 7: Modify UPSO global and local parameters using Eq. (11) and Eq. (12).

Step 8: Carry out particle's velocity and position update using Eq. (13) and Eq. (14) respectively.

Step 9: Verify the modified particle's position meets the system constraints Eq. (5) to Eq. (8); if any particles violate the limits, arbitrarily allocate the random solution to the violated position as in step 3; otherwise move to step 10.

Step 10: Whether the halting conditions are met? i.e., is $t == t_{max}$?; if yes, ideal feeder reconfiguration in a system, and the load flow solutions are achieved; if no, increase the iteration count, and go to Step 4.

The two distinctive IEEE power distribution test systems are analyzed, and the results are discussed in the accompanying section to demonstrate the skilfulness and ability of the presented work.

IV. SIMULATION RESULTS

The proposed methodology has been evaluated in two power distribution systems. The first test network is 33-bus IEEE RDS with the active power demand of 3.72 MW and reactive power demand of 2.3 MVAR [35]. The second test network is 69-bus IEEE distribution system with the active power demand of 3.8 MW and reactive power demand of 2.69 MVAR [36].

Parameters utilized for simulation studies are,

- Population size, $m = 10$
- Maximum iteration count, $t_{max} = 100$
- Inertia weight, ω is randomly selected between 0.9 and 0.4
- Social agent, $c1 = 2$ and $c3 = 2$
- Cognitive agent, $c3 = 2$ and $c4 = 2$.

A. IEEE 33-bus distribution system

The proposed strategy is simulated and evaluated in IEEE 33-bus radial distribution network to find the optimal feeder reconfiguration and optimal DG placement according to the algorithmic steps portrayed in the past section. The simulation outcomes obtained from the MATLAB software is depicted in Table 1. It is seen that the presented strategy demonstrates the quality and merits over the system with DG placement alone, and the system with only feeder reconfiguration in objective of active power loss reduction and voltage profile improvement. The bus voltage correlation chart between the radial distribution network with proposed work, with DG placement and with feeder reconfiguration is portrayed in Fig. 1. The convergence property of the proposed UPSO applied in IEEE 33-bus radial distribution network is display in Fig. 2

B. IEEE 69-bus distribution system

The UPSO technique is implemented for power loss minimization in IEEE 69-bus radial distribution network by incorporating simultaneous optimal feeder reconfiguration and optimal placement of active power delivery DG in appropriate node. The simulation outcomes in Table 2, shows the optimum position and size of DG and percentage of real power loss reduction in IEEE 69-bus radial distribution network. It is manifests that the presented method gives better results and takes less simulation time to identify the optimal DG when compared against the existing methods. Therefore, the use of the presented algorithm can also be extended to bigger power systems. The bus voltage comparison graph between the IEEE 69-bus radial distribution network with simultaneous feeder reconfiguration and DG placement, with DG alone and with feeder reconfiguration is shown in Fig. 3. The convergence property of the proposed UPSO employed in IEEE 69-bus radial distribution network is shown in Fig. 4.

V. CONCLUSION

A strategy has been presented to minimize the real power loss by simultaneous placement of optimal DG and feeder reconfiguration in IEEE 33-bus and IEEE 69-bus IEEE radial power distribution systems with the aid of UPSO algorithm. The m-script has been coded and simulated in MATLAB environment. The outcomes obtained from the simulation studies manifest that the presented method has been superior in node voltage enhancement and active power loss minimization. It has been seen that the presented technique employing UPSO shows its master quality and benefits in the viewpoint of active power loss minimization, voltage enhancement and simulation

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time. Therefore in future work, the presented method can be extended to bigger power distribution network to find the optimum rating and position of DG. Similarly, the presented scheme can also be extended to simultaneous multi DG placement and feeder reconfiguration for better loss reduction.

Table 1. Simulation result of IEEE 33-bus system

	Base case	DG	Reconfiguration	DG + Reconfiguration
Open Switches	33,34,35,36,37	33,34,35,36,37	7,9,14,32,37	7,9,14,32,37
DG location/Size (MW)	-	6 / 2.5902	-	29 / 1.1964
Active power loss (kW)	210.9876	111.0188	139.5500	98.1631
% Reduction in active power loss	-	47.3814	33.8587	53.4745
Reactive power loss (kVAR)	143.1284	81.7167	102.4000	76.8511
% Reduction in reactive power loss	-	42.9067	28.4558	46.3062

Table 2. Simulation result of IEEE 69-bus system

	Base case	DG	Reconfiguration	DG + Reconfiguration
Open Switches	69,70,71,72,73	-	14,58,61,69,70	14,58,61,69,70
DG location/Size (MW)	-	61 / 1.8725	-	61 / 0.95211
Active power loss (kW)	224.8900	83.1476	98.5720	56.1330
% Reduction in active power loss	-	63.0274	56.1688	75.0398
Reactive power loss (kVAR)	102.1200	40.4996	92.0230	52.6467
% Reduction in reactive power loss	-	60.3412	9.8874	48.4462

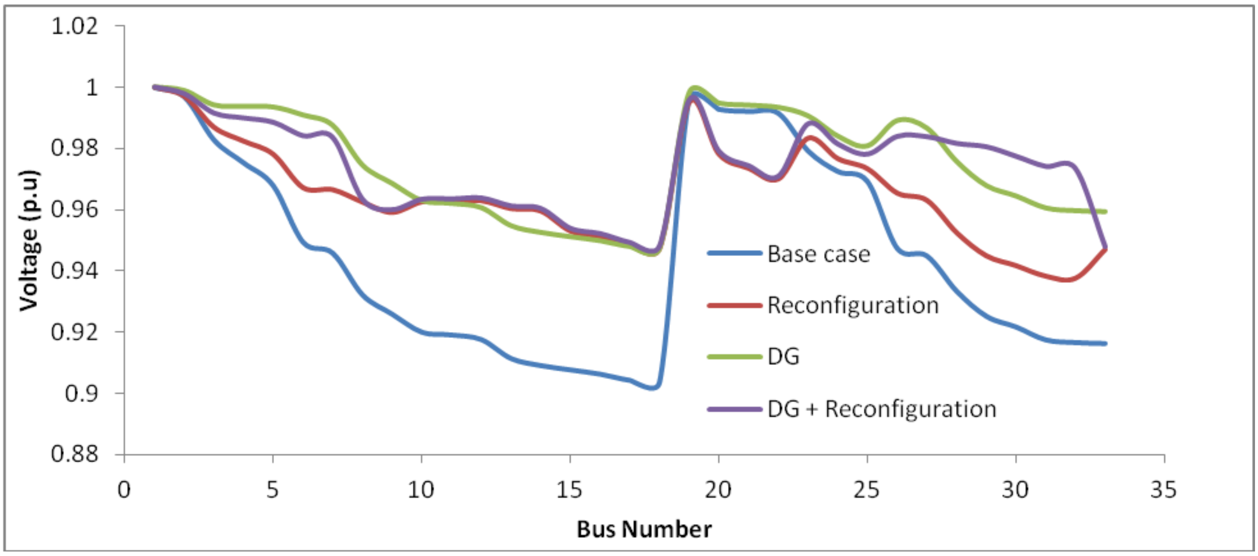

Figure.1 Comparison of bus voltage for 33-bus system

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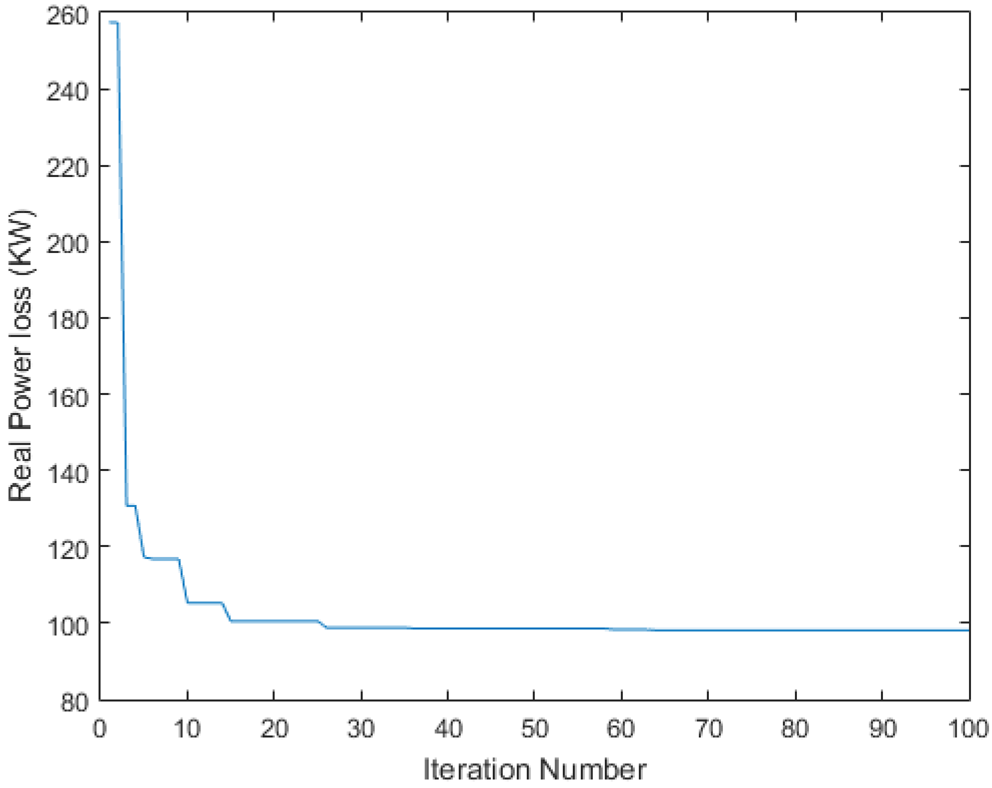

Figure.2 Convergence property for IEEE 33-bus system

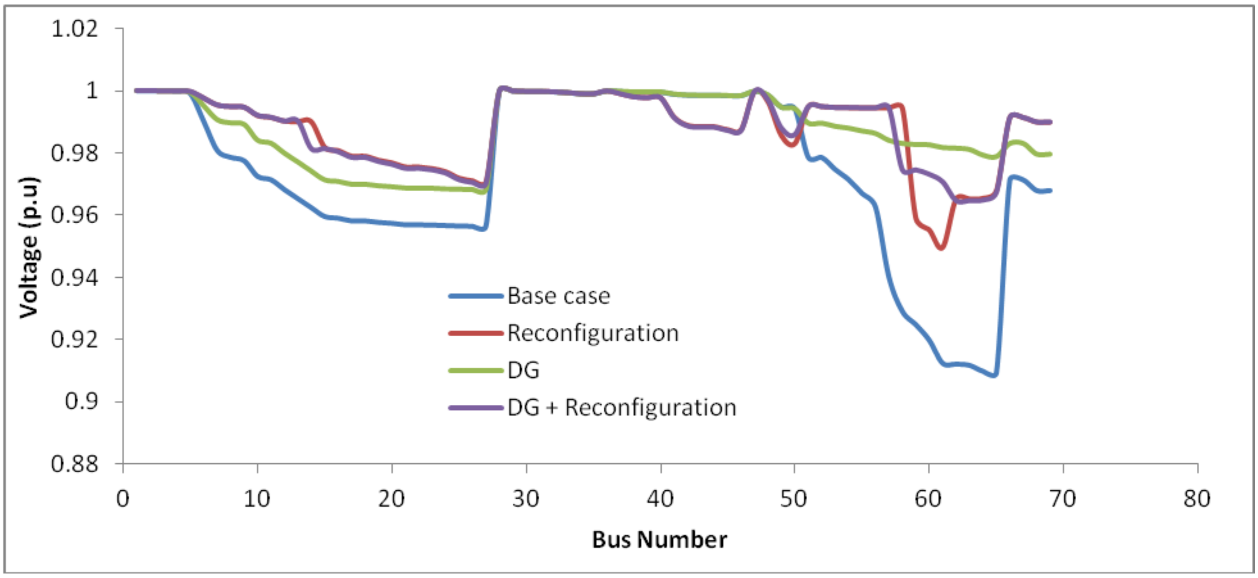

Figure.3 Comparison of bus voltage for IEEE 69-bus system

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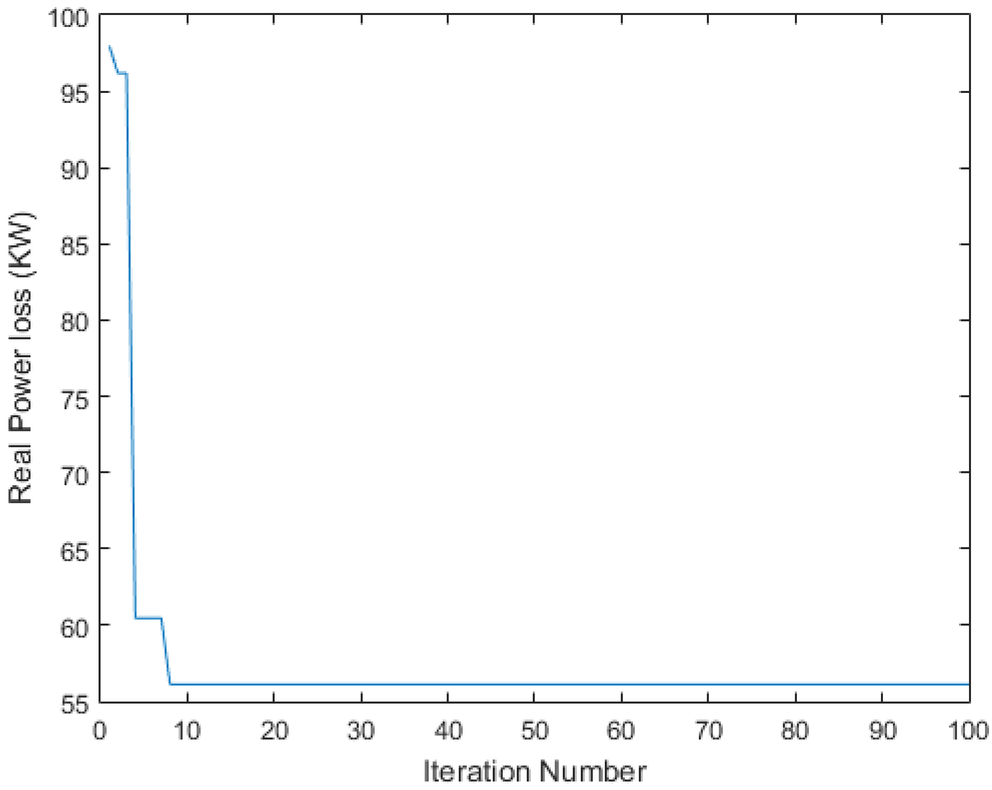

Figure.4 Convergence property for IEEE 69-bus system

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