POWER LOSS MINIMIZATION IN RADIAL DISTRIBUTION NETWORK CONSIDERING DIFFERENT LOAD LEVELS VIA AGPSO PART – I: USING HIGH PENETRATED DGs AND RECONFIGURATION

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Abstract: *Network Reconfiguration (NR) is one of the traditional methods to overcome the power loss problem and to improve the efficacy of the Distribution Network (DN). For the past two decades, optimal placement and sizing of DG units had played a significant role in minimizing the power loss as well as node voltage improvement. The impact of power loss reduction will be more, if both DG units and NR are combined together. This paper proposes an application of Autonomous Group Particle Swarm Optimization (AGPSO) to solve the network reconfiguration problem with optimal placement and sizing of four DG units under four different cases with an objective to minimize real power loss in Radial Distribution Network (RDN) subject to satisfying operating constraints. Further, this paper considers three different load levels for optimal DG placement with NR to investigate the effectiveness of the proposed method. The proposed method has been tested on standard IEEE 33 and 69 bus DN and the results are compared with previous published methods. Simulation results reveal that the proposed method minimizes the real power loss and voltage deviation in an effective and efficient manner.*

Key words: *DG units, Network reconfiguration, AGPSO, Radial Distribution Network, Power loss*

1. INTRODUCTION

Distribution Networks are normally functioning under heavily loaded condition due to competition in energy market, steep increase in electrical energy demand and environmental constraints. As load increases, the power loss (I^2R) increases with poor voltage regulation. Alternatively, high reactive power flows in a network results in increased power losses. It is understood that the power demand and power loss decide the power generation. In developed countries the maximum power loss is 10% only as against from 4% to 7%. However, in India the average Transmission and Distribution losses have been estimated around 26% to 27% of the power generated [1]. The only alternative to improve the efficacy of the DNs is minimization of power loss. Distribution utilities have to maintain node voltage between the limits which is essential for correct operation of customer loads. Its deviation from the nominal value may be harmful and expensive causing an ageing effect on them. To promise low power loss, improvement in node voltage profile and improvement in power factor, several methods are being followed.

Several authors have proposed different techniques for minimizing the power loss and bus voltage improvement for DN. Network Reconfiguration (NR) has been a traditional method for mitigation of the above problem. NR is a very important operation tool to operate the distribution network at minimum cost, smoothening out the peak demands, improving the voltage profiles, enhancing the quality and reliability of the DN as well as a fault management technique. NR is a process for selection of the best set of branches to be opened, one from each loop, such that the reconfigured DN improves system performance by way of reducing the power loss and system cost subject to maintaining the radiality structure during reconfiguration. A number of algorithms based on soft computing techniques had been developed to solve the NR problem [2-9].

The power loss reduction and bus voltage improvement achieved after NR may be inadequate and may not solve the anticipated power loss minimization. Integration of DG units into DN is expected to play an increasing role in modern electrical power systems. It is predicted that the penetration of DG units in the RDN will exceed more than 25% of the total generation in the anticipatable future [10].

During the last two decades, various research activities based on introduction of DG units into DN to analyse technical and economical impacts such as reduction in line losses, improvement in bus Voltage, improvement in security and reliability, grid strengthening, peak load shaving, improved power quality, fuel saving, electricity price, planning cost and efficacy had been carried out which made the researchers to focus their research on DG placement [11-13]. In order to maximize the above benefits, DG placement and sizing need to be optimized. Traditionally DN has been treated as a passive circuit. However, the direction of network becomes multidirectional when DG is inserted in the network which changes the network from passive to active. During the last decade, optimal allocation and capacity determination of DG units using various optimization techniques had been developed [14-19].

The above discussed papers considered either NR or DG alone. The power loss reduction and improvement in bus voltage in the RDN can be achieved by combined effect of DNR with either capacitor or DG in a better manner than individual optimization of each task and also the efficiency gets increased thereby reduction in cost. However power loss reduction achievement and bus voltage improvement via NR with DG will be more effective and efficient than the combined effect of DNR with capacitor. Therefore optimal placement of DGs with NR has been focused in this paper. With power loss as objective function optimal sizing of four DG units with and without NR under five cases using PSO has been proposed in [20]. NR and optimal DG sizing simultaneously to reduce the cost and increase its efficiency under five distinct cases using EPSO has been proposed in [21]. Using EP / EP and GA as optimization tool optimal sizing of four DG units with NR to minimize the real power loss has been discussed in [22,23]. Optimal sizing of four DGs with NR using GA and PSO in Radial DN has been presented in [24]. NR in the presence of four small DG units injecting both real and reactive power using ACS / GA / GA and ACO have been discussed in [25,26,27]. With four small DG units in the DN which injects only real power, NR has been performed using Tabu-search and Simulated Annealing / GA to minimize real power loss has been proposed by [28,29,30].

Some drawbacks were witnessed in the above discussed papers. DG allocation after NR and simultaneous optimal placement and sizing of DG units with NR was not done in [20-30]. NR after optimal DG allocation and sizing was not done in [22]. In [20,21,23], the total real power injected by the DG units was found to be more than the total real power demand of the test system considered in that. This leads to stability issues in the particular feeder as well as adjacent feeders, and also it shows reverse impact on power losses reduction. To validate the objective function, only one case study was considered in [20,21,23,24,26,27,28]. In [25-30] the authors pre-fixed the DG units in the DN, that is optimal DG penetration limit was set by the user before beginning of the optimization. Hence DG sizing is not an optimal value. The above said deficiencies were overcome by this research work, by considering four DG units with NR under five different configurations (except case I) using this proposed method. Since the time varying loads have been considered indispensable, they have been used to ascertain the actual impact of DG units with NR for power loss reduction. Therefore three different time varying loads have been considered such as 50%, 100% and 160%.

Since the problem is of large dimensional, mixed integer, complex combinatorial and nonlinear in nature, the most widely used way to solve the problem is to use meta-heuristic optimization method [31]. Though meta-heuristic optimization technique is found to be successful in determining DG size, optimal placement, NR, loss minimization and bus voltage improvement etc. in radial DN, some of the Artificial Intelligent techniques have some weaknesses such as suffer from local optimality, requiring large time for simulation, premature or slow convergence etc. [32,33]. PSO also have drawbacks such as partial optimism, scattering problem, slow convergence in refined search stage, weak local search ability and possible entrapment in local minima [34]. Therefore, there is an urge to introduce a new, simple, effective, fast and efficient population based optimization algorithm to solve NR with optimal DG units simultaneously to overcome the above demerits.

In this study, a new meta-heuristic optimization algorithm of best, durable and proficient which is a modification of PSO utilizing the concept of autonomous groups called AGPSO.is selected to solve the objective function. AGPSO [35] has been powerful in solving wide range of optimization problems which is used in this paper for optimal allocation and capacity determination of DG units along with network reconfiguration in DN. The main drawbacks of PSO [34] had been eliminated by [35] were taken for achieving optimum solution globally. This optimization approach is tested and evaluated on two test systems (IEEE 33 and 69 bus system), (i) Suggesting AGPSO for three different load levels to solve the objective function and (ii) Assessment of both real and reactive power loss and identification of maximum branch power loss for all the cases and scenarios (iii) For the first time, optimal placement of four DGs with NR under three different load levels have been included as features of this paper.

The remaining paper is structured into 5 sections. Section 2 explains the mathematical formulation that consists of fundamental power flow and objective function to perform the placement and sizing of DG units with NR. Section 3 discusses the proposed methodology (AGPSO) and its ability to solve the optimization problem and the implementation of AGPSO algorithm for the proposed problem. Discussion on the simulation and the results have been done in Section 4 and finally Section 5 concludes with the results obtained followed by references.

2. Problem Formulation

The objective function is to minimize the real power loss in the DN while satisfying both system equality and inequality constraints.

2.1 Objective function

Minimize $\text{Fit} = \left[\text{TP}_{\text{LOSS (net)}}\right]$ (1)

Equality Constraints

$$P_{MS} + \sum_{t=1}^{NDG} P_{DG(t)} - \sum P_D - TP_{LOSS} = 0 \quad (2)$$

$$Q_{MS} - \sum Q_D - TQ_{LOSS} = 0 \quad (3)$$

Inequality Constraints

$$V_{(t)}^{min} \le V_{(t)} \le V_{(t)}^{max} \quad (4)$$

$$P_{DG_{(t)}}^{min} \le P_{DG(t)} \le P_{DG_{(t)}}^{max} \quad (5)$$

$$\sum_{t=1}^{NDG} P_{DG(t)} \le (\sum P_D + TP_{Loss}) \quad (6)$$

Where

$$TP_{LOSS(net)} = \frac{TP_{LOSS(AC)}}{TP_{LOSS(BC)}}$$

Further, perfect radiality structure must be followed so as to avoid excess load current flow and also no customer should be left unconnected during reconfiguration.

2.2 Load Flow

Power flow study plays a vital role in the proper planning of power transfer to meet the various types of load demands in the present-day scenario; it is most significant for the effective handling of the task of the entire power system network. Most matrix-based load flow methods such as Gauss-seidal, Newton-Raphson and Fast de-coupled power flow methods were inferior to solving power balance equations for DN because of high R/X ratio and radial nature of the network [36,37]. To overcome the above difficulties, load flow based on ladder theory was developed [38,39]. Later it had been reported that it does not obtain solutions for several instances. In this paper, recursive function and a linked-list data structure designed power flow [40] has been used which has an advantage of the radial nature of DN and also the ability to update easily to accommodate the reconfiguration and embedded generation.

3. Autonomous Groups P S O (AGPSO)

3.1 Particle swarm optimization (P S O)

Particle swarm optimization (PSO) is a population based stochastic optimization technique [41], inspired by the social behavior of bird flocking or fish schooling. In PSO, each single solution is a 'particle' in the search space. All the particles have fitness values which are evaluated by the fitness function to be optimized, and also have velocities which direct the flying of the particles. The particles fly through the problem space by following the current optimum particles.

PSO is initialized with a group of random particles (solutions) and then it searches for optima by updating generations. In every iteration, each particle is updated by following two "best" values. The first one is the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called *pbest*. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called *gbest*. In the course of iterations, each particle adjusts its position and velocity as follows:

$$v_{iG}^{t+1} = (w \times v_{iG}^{t}) + (C_1 \times rand \times (pbest_{iG} - x_{iG}^{t})) + (C_2 \times rand \times (gbest_{iG} - x_{iG}^{t})) \quad (7)$$

$$x_{iG}^{t+1} = x_{iG}^{t} + v_{iG}^{t+1} \quad (8)$$

3.2 Proposed method (AGPSO)

In this paper, PSO is modified by a mathematical model of different functions with diverse slopes, curvatures, and interception points being employed to tune the socio and cognitive constants of C_1 and C_2 parameters which were given in (7) to generate particles of different behaviors to achieve the desired solution. The Standard PSO after the above modification has been named as Autonomous Groups Particle Swarm Optimization (AGPSO). AGPSO is mainly applied to alleviate the two major problems of trapping in local minima and slow convergence rate of PSO in finding the optimal position of switches and placement and sizing of DG units. Detailed description about AGPSO is available in [35] with the merits of AGPSO compared with variants of PSO. Updating strategies to tune the C_1 and C_2 parameters are given in [35].

3.3 Implementation of AGPSO for the chosen problem

The application of AGPSO for minimization of real power loss with improvement in node voltage by optimal allocation and sizing of DG units along with NR in the RDN is illustrated with the help of the standard IEEE 33 and 69 bus test systems are explained in this segment. To find the optimal location for DG units, change in injection of real power by DG units at appropriate places, the real and reactive power loss of the entire network get altered. For reconfiguration, closing tie-switches by simultaneously opening of sectionalizing switches keeping all possible radiality structures are generated initially.

Step 1: Initialize the particles (x_i) of PSO randomly within the boundary limits given in **Table 1.**

$$X_{(i)} = \begin{bmatrix} \textit{DG}\text{ bus limits} & \text{DG sizing limits} & \text{Tie-switch status} \\ (1,3,5,7) & (2,4,6,8) & (9\text{ to }13) \\ \multicolumn{3}{l}{\text{Status of opening of sectionalizing switches (14 to 18)}} \end{bmatrix}_{(18\times1)}^{T} \quad (9)$$

Where, $x_{(i)}$ - Parameters of the variables given in (9) correspond to the i^{th} data of x_i. The proposed particles consist of position of tie-switches, optimal DG node and size. Thus, the number of variables for the simultaneous analysis is equal to eighteen. To find optimum allocation and sizing of DG units without NR, the proposed particles can be written as:

$$X_{(i)} = \begin{bmatrix} DG \text{ bus limits} & \text{DG sizing limits} \\ (1,3,5,7) & (2,4,6,8) \end{bmatrix}^T_{(8\times1)} \quad (10)$$

The number of variables are equal to eight for optimal placement of DG units lone. Four for optimal bus for DG placement and another four for optimal DG sizing. Only the particles that satisfy all the constraints will be considered as the initial population.

Step 2: Particles x_i are randomly split into some predefined autonomous groups with Beneficiary functions according to Table 1 given in [35].

Step 3: Calculate *gBest*, *pBest*, and the fitness given in (1) of the particles x_i at each iteration.

Step 4: For each particle, the coefficients C_1 and C_2 are updated using its group's strategy.

Step 5: Velocities v_i and positions of particles x_i will be updated using (7) and (8).

It should be noted that when the particles move from the current position $X_{(i)}$ to the new position $X_{(i+1)}$ substituting (9) and (10) into (7) and (8), result in the change in parameters of variables.

Values corresponding to the solution vectors (SV) as mentioned in (9) for the proposed problem is as shown in **Table 1.** The new SV are generated and updated using stages 2 to 5. With new generated vectors that have lesser objective function of minimizing the real power loss and bus voltage improvement (selected from the newly updated population), previous inferior vectors will get replaced. This procedure is repeated until maximum number of iterations (100) are reached. Three objective function (AGPSO 1, AGPSO 2, AGPSO 3) are obtained at the end of the maximum iterations, the one, which has least value is considered as the best value.

Table 1 Typical value of Agents (cases II to VI)

Variables	Values of SV
$X_{(1)}$ $X_{(3)}$ $X_{(5)}$ $X_{(7)}$	Bus number 2 to 33 / 2 to 69
$X_{(2)}$ $X_{(4)}$ $X_{(6)}$ $X_{(8)}$	0.1 MW to 1.0 MW - 50% load 0.3 MW to 1.8 MW - 100% load 0.3 MW to 2.5 MW - 160% load
$X_{(9)}$ - $X_{(13)}$	Status of closing of tie-switches (33 to 37 / 69 to 73)
$X_{(14)}$ - $X_{(18)}$	Opening of sectionalizing switches (2 to 32 / 2 to 68) corresponds to the closing of tie-switches

4. SIMULATION RESULTS AND DISCUSSION

To demonstrate the application of the proposed method for minimization of power loss and improvement in node voltage, two case studies such as standard IEEE 33 bus test system and standard IEEE 69 bus test system are considered in this paper for analysing the effectiveness of AGPSO. To get optimal network, optimal node of DG units and the status of tie-switches and position of sectionalizing switches are to be known. The base MVA and base kV for both the test cases are 100 and 12.66 respectively. The simulation is developed in MATLAB R 2013a and has been carried out in an Intel i5 processor (4th generation) with 8GB RAM running on windows 8.1 OS. The minimum and maximum voltages are set as 0.95 p.u. and 1.05 p.u.

To minimize the real power loss and improvement in node voltage, six different cases are considered in this work to investigate the supremacy of the proposed method (Cases I to VI). Three load levels (50%, 100% and 160%) for each test case is considered to validate the effectiveness in power loss reduction. For all the cases (except case I), minimum real power injection is assumed to be less than or equal to the total real power demand of the system plus active real power loss.

Case I: Network Reconfiguration technique is employed with all the tie-switches opened initially (base case network) for both the test system to examine the power loss reduction for three load levels

Case II: Four DG units are allocated at optimal locations using the proposed method in both the test systems to analyse the impacts of DG units without NR considering three load levels.

Case III: The conditions of the systems are similar to case II, However Network Reconfiguration has been done on both the test systems after optimal allocation of DG units for all the three load levels.

Case IV: Optimal DG sizing simultaneous with NR keeping the optimal DG bus obtained under case II has been done for three different load levels to compare the power loss reduction with case III.

Case V: The conditions of the systems are similar to case I, but optimal allocation and sizing of four DG units in the reconfigured DN has been done to access the impact of power loss after NR.

Case VI: Optimal placement and sizing of four DG units Simultaneous with NR along the DN has been applied to ascertain the power loss reduction under three different load levels.

4.1 Case study details - 33/69 bus Radial DN

IEEEE 33 test system is a hypothetical test system which has 33 nodes, 37 edges, and 5 looping branches with the system voltage of 12.66 KV. The total real and reactive power loads for this system are 3715 KW and

2300 KVAr respectively. The tie lines which are normally opened are from 33 to 37 and 1 to 32 are normally closed sectionalizing switches. Node No.1 (main Sub-station node) is considered as slack bus and the remaining nodes are considered as load buses. The line data and load data for this network are taken from **[2]**. First, the base case load flow is conducted and the results pertaining to real and reactive power loss with least value of node voltage and branch power loss have been recorded.

For this configuration, the total system real and reactive power loss, worst bus voltage **[2]** and the maximum branch power loss are indicated in **Tables 2 and 3**. The total real power supplied by the main source is 3926 KW. **Figure 1** shows the base case network for IEEE 33 bus test system. **Tables 2 and 3** show the results of the first test system for 50%, 100% and 160% load levels.

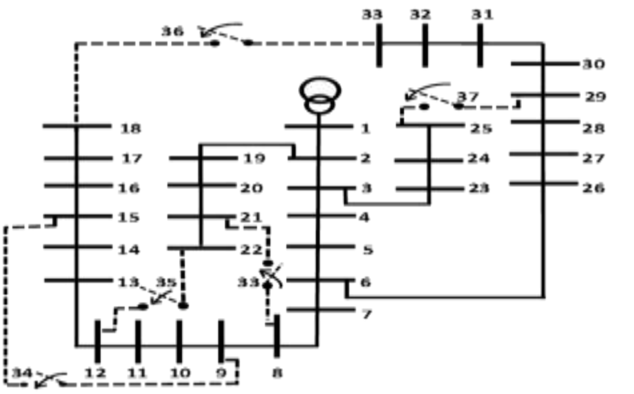

Figure 1 - Standard 33 Bus Test system (Base case)

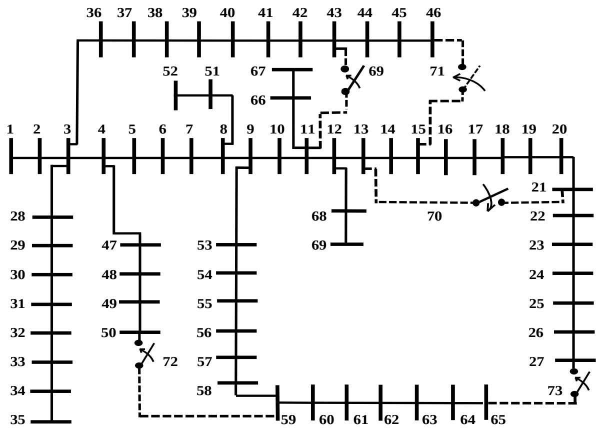

Figure 2 – Standard 69 Bus Test system (Base case)

The next test system consists of 69 nodes, 5 looping lines, 7 lateral feeders and edges on every branch of the system. The total connected loads on this hypothetical system are 3802.19 kW and 2694.60 KVAr respectively with system voltage as 12.66 KV.

For the purpose of load flow calculation, 12.66 KV is taken as base KV. Bus No.1 (main Sub-station bus) is considered as slack bus and all the remaining buses are considered as load buses. Tie switches which are normally opened are from 69 to 73, and 1 to 68 are normally closed sectionalizing switches. The line data and load data for this network were taken from **[9]**. For both the test system, the parameter details such as agent size and No. of iterations are selected as 800 and 100 respectively and main source voltage is assumed to be fixed as 1+j0 p.u.

The system total real and reactive power loss, worst bus voltage **[9]** and maximum branch power loss are mentioned in **Tables 4 and 5**. The total real power supplied by the main source is 4027.185 KW. **Figure 2** shows the base case network for IEEE 69 bus system. Similar to IEEE 33 test bus system, IEEE 69 bus test system is also simulated for six different cases and three different load levels **Tables 4 and 5** confer the effectiveness of the proposed method (AGPSO).

4.2 Discussion – 33 bus (50%, 100% & 160%)

Considering DNR alone for Light load (50% load), real power loss reduction of 38.307% can be achieved using the proposed method with the bus voltage improvement of 0.01856 p.u. Maximum real power loss reduction achieved under case II is 73.888% with optimal DG penetration of 82.359%. The bus voltage improvement compared to base case is 0.03203 p.u. At the same time the power loss further reduced by 6.15536% after NR for case III with the bus voltage difference of 0.00159 p.u compared to case II. However, the difference in power loss reduction between case III and case IV is 0.7723% only and also the bus voltage difference is insignificant. Compared to case I, the power loss minimization after optimal placement of four DG units, is 44.3017% with the improvement in bus voltage of 0.01642 p.u. Compared to base, the power loss reduction achieved under case VI is 83.7514% with the bus voltage enhancement of 0.03569 p.u.

Considering Medium load (100% load), power loss reduction of 40.4% is gained using NR with progress in bus voltage of 0.03988 p.u which is better than **[2-5,18,19,21,22]**. By 82.1192% DG penetration in the DN, the real power loss achieved by the proposed method is 71.19% with bus voltage enhancement of 0.06687 p.u. The solution obtained using the proposed method is better than **[13-17, 24-27].** Meanwhile, by case III the power loss reduced further by 7.06% after NR. By comparing **[20,21,26]**, it is understood that the proposed method yields more power loss reduction. Considering case IV, the power loss reduction difference compared to case III is 3.057 KW with 1.81% less DG penetration. From **[21,26,27],** it is evident that case IV is better in minimizing real power loss reduction. DG units at four optimal locations in the reconfigured DN, yields an additional power loss reduction of 40.19% compared to case I with improvement in bus voltage of 0.03136 p.u. Case VI is found to be the highest in minimization of power loss

Table 2 Switches Topology & Losses - 33 Bus

Case	Switches Opened	P_{Loss} (KW)	Q_{Loss} (KVAr)	P_{Loss} reduction
50% Load				
B.C	33, 34, 35, 36, 37	**48.79**	33.049	------
I	7, 14, 10, 32, 28	**30.1**	25.0517	**38.307%**
II	33, 34, 35, 36, 37	**12.74**	8.9099	**73.8881%**
III	7, 12, 9, 36, 28	**9.7368**	8.5853	**80.043%**
IV	7, 12, 10, 36, 28	**9.36**	8.5194	**80.816%**
V	7, 14, 10, 32, 28	**8.4852**	8.6154	**82.609%**
VI	7, 13, 9, 31, 28	**7.9277**	8.6133	**83.7514%**
100% Load				
B.C	33, 34, 35, 36, 37	**211.004**	143.135	**------**
I	7, 14, 10, 32, 28	**125.76**	104.65	**40.4%**
II	33, 34, 35, 36, 37	**59.539**	41.663	**71.783%**
III	7, 13, 9, 30, 28	**43.309**	43.633	**79.4748%**
IV	7, 12, 11, 36, 28	**42.088**	37.661	**80.0534%**
V	7, 14, 10, 32, 28	**40.958**	37.193	**80.589%**
VI	7, 14, 9, 32, 28	**39.614**	40.555	**81.226%**
160% Load				
B.C	33, 34, 35, 36, 37	**603.48**	410.22	**------**
I	7, 14, 10, 32, 28	**340.836**	283.544	**43.5216%**
II	33, 34, 35, 36, 37	**167.86**	117.29	**72.185%**
III	7, 12, 9, 32, 28	**120.12**	106.49	**80.095%**
IV	7, 12, 10, 32, 28	**114**	101.93	**81.11%**
V	7, 14, 10, 32, 28	**108.03**	105.51	**82.1%**
VI	7, 13, 9, 30, 28	**97.463**	96.881	**83.85%**

which is 81.226% compared to base case with bus voltage enhancement of 0.08589 p.u.

The power loss reduction obtained using the proposed method under case I considering heavy load (160% load), is 43.5216% with bus voltage enhanced by 0.07081 p.u. By optimal DG penetration of 75.9071%,the real power loss reduction of 72.1847% is gained with bus voltage increase of 0.11749 p.u. After case III, the power loss further has reduced by 7.911%. However the power loss difference between case III and IV is 1.014%.The bus voltage increase compared to case II is insignificant. By optimal DG penetration of 81.2679% in the reconfigured DN, extra power loss reduction of 38.577% is attained compared to case I with the bus voltage difference of 0.05563 p.u. Considering case VI, Power loss reduced by 83.85%, with optimal DG penetration of 80.657% with bus voltage enhancement of 0.12697 p.u compared to B.C.

From the above discussion it is concluded that case VI has been proved to be the best in minimizing the power loss as well as improvement in bus voltage compared with cases III to V in terms of eminence of results under all load levels. It is evident that cases III

Table 3 DG details, Branch loss & bus voltage`- 33bus

Case	DG Bus & Size (KW)	Branch $P_{Loss\ (max)}$ (KW) / (Branch)	V_{min} (p.u)
Load : 50%			
B.C	-------	12.176 / (2 – 3)	0.95396
I	-------	6.42184 / (2 – 3)	0.97252
II	7 (420) 14 (315)	2.7835 / (2 – 3)	0.98599
III	24 (485) 31 (350)	1.698 / (2 – 3)	0.98758
IV	7 (399) 14 (418) 24 (477) 31 (360)	1.6917 / (2 – 3)	0.98826
V	25 (532) 6 (305) 8 (608) 32 (196)	1.6473 / (2 – 3)	0.98894
VI	6 (304) 18 (251) 8 (462) 29 (621)	1.4346 / (2 – 3)	0.98965
Load : 100%			
B.C	-------	52.077 / (2 – 3)	0.90376
I	-------	26.76 / (2 – 3)	0.94364
II	6 (839) 24 (1025)	12.586 / (2 – 3)	0.97063
III	14 (646) 31 (714)	7.6353 / (24 – 25)	0.97388
IV	6 (575) 24 (991) 14 (904) 31 (683)	8.1449 / (23 –24)	0.97549
V	6 (405) 18 (316) 21(740) 29 (1459)	8.1836 / (2 – 3)	0.97625
VI	6 (541) 24 (785) 8 (1215) 30 (888)	7.6598 / (23 – 24)	0.9781
Load : 160%			
B.C	-------	146.53 / (2 – 3)	0.83598
I	-------	72.2775 / (2 – 3)	0.90679
II	7 (1274) 24 (1276)	34.875 / (2 – 3)	0.95347
III	14 (1047) 30 (1373)	21.294 / (23 – 24)	0.9558
IV	7 (860) 24 (1273) 14 (1386) 30 (1418)	21.434 / (23 –24)	0.95714
V	6 (994) 8 (1953) 25 (1742) 32 (632)	21.246 / (23 – 24)	0.96142
VI	26 (927) 21 (1539) 25 (1798) 32 (1017)	18.245 / (2 – 3)	0.96295

GA, EP, PSO and EPSO **[20, 21,25-27]**. Finally the reductions of P_{Loss} & improvement in bus voltage have been efficient and effective in a better manner by this proposed method Node voltages obtained from cases I to VI for all load levels are displayed in **Figures 3 to 5.**

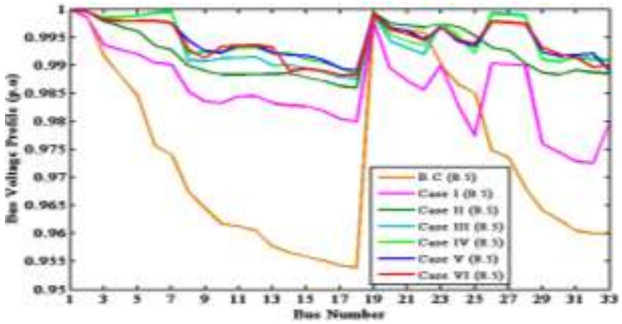

Figure 3 Bus voltage comparison – 50% - 33 Bus

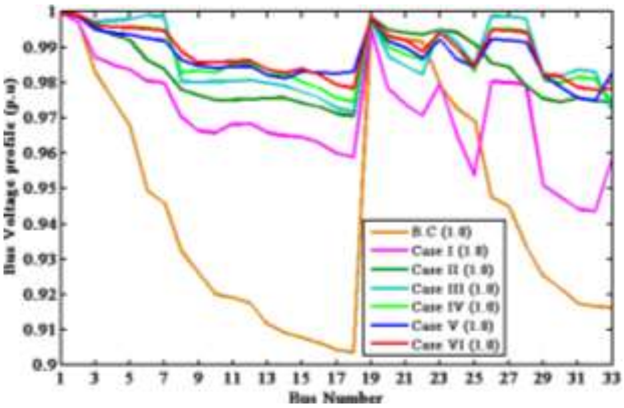

Figure 4 Bus voltage comparison – 100% - 33 Bus

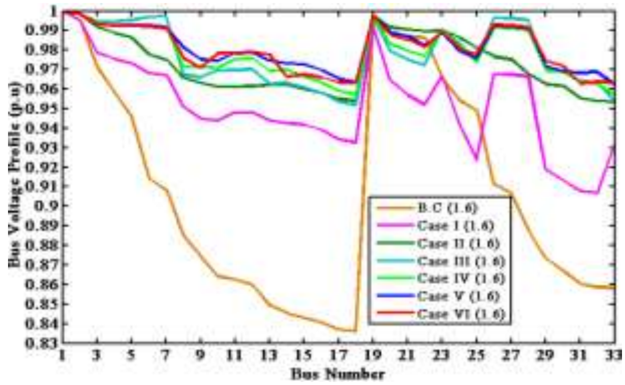

Figure 5 Bus voltage comparison – 160% - 33 Bus

Table 4 Switches Topology & Losses - 69 Bus

Case	Switches Opened	P_{Loss} (KW)	Q_{Loss} (KVAr)	P_{Loss} reduction
50% Load				
B.C	69 70 71 72 73	**51.595**	23.546	--------
I	69 70 14 58 61	**23.608**	22.087	**54.2436%**
II	69 70 71 72 73	**12.501**	5.9121	**75.771%**
III	69 70 14 55 63	**7.7346**	6.7802	**85%**
IV	69 70 13 57 64	**6.8301**	6.5591	**86.762%**
V	69 70 14 58 61	**6.6744**	6.4546	**87.065%**
VI	69 70 14 56 63	**6.5015**	5.9404	**87.4%**
100% Load				
B.C	69 70 71 72 73	**224.95**	102.14	**--------**
I	69 70 14 58 61	**98.57**	92.023	**56.18%**
II	69 70 71 72 73	**59.983**	27.495	**73.335%**
III	10 70 12 56 64	**33.749**	33.137	**85%**
IV	69 70 12 58 63	**31.816**	28.108	**85.8564%**
V	69 70 14 58 61	**30.895**	30.524	**86.266%**
VI	69 70 13 58 61	**29.483**	27.536	**86.894%**
160% Load				
B.C	69 70 71 72 73	**652.38**	294.19	**--------**
I	69 70 14 58 61	**267.07**	248.61	**59.0622%**
II	69 70 71 72 73	**165.23**	84.163	**74.673%**
III	10 70 13 58 63	**86.794**	91.157	**86.696%**
IV	69 70 13 56 63	**81.903**	80.854	**87.4455%**
V	69 70 14 58 61	**81.213**	80.921	**87.5513%**
VI	69 70 14 58 61	**80.743**	74.914	**87.6233%**

4.3 Discussion – 69 bus (50%,100%&160%Load)

To Start with examining only NR for light load (50% load) level, the power loss reduced by 54.2436% with bus voltage improvement of 0.01867 p.u. which is better than **[18,19]**. By optimal placement of four DG units with 86.5334% DG penetration, the power loss minimized by 75.7787% with bus voltage enhancement of 0.03052 p.u. compared to B.C. However, power loss reduction under case III, has increased by 9.2381% and further compared to case II after NR. Power loss reduction increase of 1.7531% compared to case III is seen with bus voltage increase of 0.00228 p.u. Considering the cases V and VI, there is not much difference in power loss reduction and bus voltage improvement compared to case IV.

Reduction in power loss by 56.1725% by NR with bus voltage improvement of 0.04028 p.u. has been obtained considering Medium load (100% load) using the proposed method. By comparing [4,6 – 8,18,23], it is witnessed that the proposed method seems to be better in minimizing the power loss as well as bus voltage improvement. Real power loss reduction achieved by optimal allocation and sizing of four DG units under case II is 73.788% with optimal DG penetration of 83.76%. The real power loss reduction obtained by NR after case II is 84.484% which is 11.3072% in excess compared to case II. The bus voltage improvement between case II & B.C is 0.07115 p.u. and between case III and case II is 0.00101 p.u. Nevertheless the power loss reduction difference between cases IV, V and VI with case III it is 1.347855%, 1.782174% and 2.4445% respectively. The bus voltage difference between case VI and B.C is 0.07504 p.u.

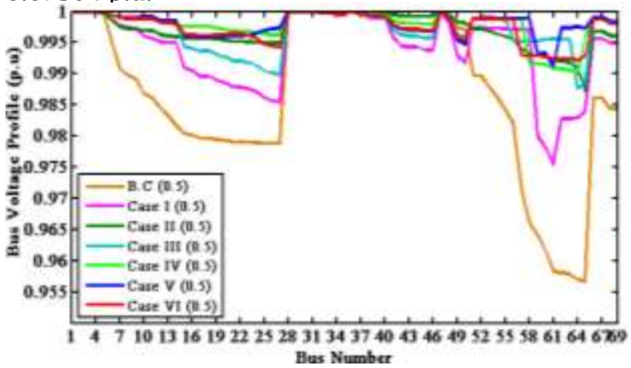

Figure 6 Bus voltage comparison – 50% - 69 Bus

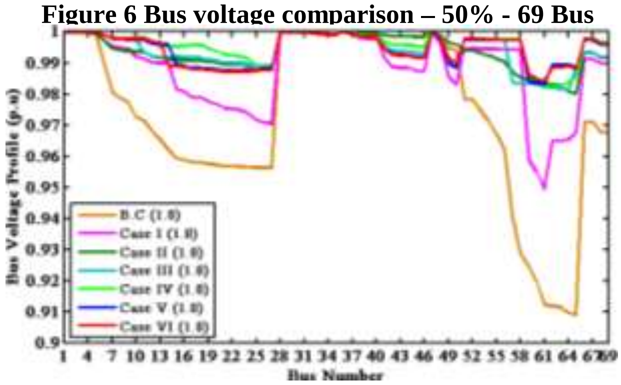

Figure 7 Bus voltage comparison – 100% - 69 Bus

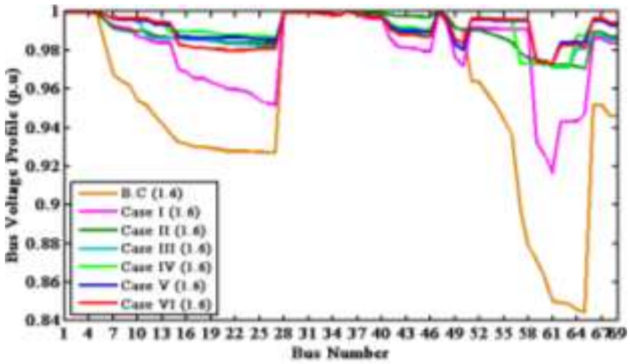

Figure 8 Bus voltage comparison – 160% - 69 Bus

Table 5 DG details, Branch loss and bus voltage`- 69bus

Case	DG Bus & Size (KW)	Branch $P_{Loss\,(max)}$ (KW) / (Branch)	V_{min} (p.u)
	Load : 50%		
B.C	---------	11.265 / (56 – 57)	0.95668
I	---------	8.9394 / (50 – 59)	0.97535
II	11 (253) 50 (359)	2.4581 / (56 – 57)	0.9872
III	18 (189) 61 (844)	2.2375 / (50 – 59)	0.98762
IV	11 (264) 50 (380) 18 (227) 61 (790)	2.8413 / (50 – 59)	0.99059
V	11 (287) 27 (129) 64 (208) 61 (731)	1.8737 / (50 – 59)	0.99115
VI	11 (258) 21 (324) 50 (296) 61 (731)	1.9442 / (50 – 59)	0.99217
	Load : 100%		
B.C	---------	49.684 / (56 – 57)	0.90919
I	---------	37.7043 / (50 – 59)	0.94947
II	11 (524) 49 (769)	12.173 / (56 – 57)	0.98034
III	17 (365) 61 (1715)	14.307 / (50 – 59)	0.98135
IV	11 (536) 49 (830) 17 (860) 61 (1370)	10.086 / (50 – 59)	0.98257
V	11 (493) 64 (490) 36 (808) 61 (1431)	9.6608 / (50 – 59)	0.98314
VI	11 (522) 64 (481) 49 (821) 61 (1342)	9.5589 / (50 – 59)	0.98423
	Load : 160%		
B.C	---------	146.49 / (56 – 57)	0.84449
I	---------	103.49 / (50 – 59)	0.91648
II	11 (871) 18 (609)	34.16 / (56 – 57)	0.97078
III	64 (491) 61 (2282)	28.942 / (50 – 59)	0.97127
IV	11 (802) 18 (572) 64 (593) 61 (2405)	29.255 / (50 – 59)	0.97191
V	11 (765) 21 (492) 64 (565) 61 (2269)	27.539 / (50 – 59)	0.97276
VI	11 (860) 50 (1127) 64 (788) 61 (2171)	27.28 / (50 – 59)	0.97304

From Tables 4 & 5, the real power loss reduction obtained using NR for 160% load is found to be 59.0622% with bus voltage improvement of 0.07199 p.u. compared to B.C. which is greater than [18,19]. Optimal allocation of four DG units shrinks the real power loss upto 25.32% with bus voltage enhancement of 0.12629 p.u compared to B.C. In case III, the real power loss reduction obtained after NR is 12.0235% greater than case II. The power loss reduction difference between cases III and IV is 2.17426%. However the improvement in bus voltage as well as power loss reduction seemed to be insignificant by comparing cases IV, V and VI.

From the above, it is obvious that the real power loss reduction and improvement in bus voltage achieved by the developed technique under cases I and II is found to be better when compared with other methods for 100% load level. Case VI is proved to be best in minimizing the real power loss as well as bus voltage improvement when compared with cases III to V. As a final point, the overall performance of the proposed method is found to be commendable in giving more real power loss reduction and enhancement in bus voltage. Node voltage obtained under cases I to VI is displayed in Figures 6 to 8 for three load levels.

5. CONCLUSION

This work presented an efficient AGPSO technique to find the best suitable structure of the RDN with DG units keeping power loss minimization as objective function via different combination of DG units with NR. The performance of PSO has been improved by modifying the key parameters (C_1, C_2 and W) utilizing the concept of autonomous groups called AGPSO. Six different cases comprising DGs with and without NR considering three different load levels (50%,100% and 160%) have been developed to validate the supremacy of the proposed method in minimizing real power loss. The proposed method is tested on standard IEEE 33 and 69 bus test system.

It has been proved that the optimal placement of four DG units with NR simultaneously (case VI) yields more power loss reduction compared with other cases under all the three load levels. From the outcomes, it is clear that, greater impact on power loss minimization is noticed in reconfigured DG integrated RDN. However, allocation beyond four DG units with and without NR may not yield significant power loss reduction and also uneconomical. The results have proved that the proposed method (AGPSO) is an effective and efficient method for minimization of real power loss and bus voltage improvement.

Nomenclature

BC - Base Case
AC - After Compensation
MS - Main Source
TNB - Total No. of Buses

TB - Total No. of branches (TNB-1)
N_{DG} - Total No. of DG units
P_{MS} - Total real power supplied by the Main Source in KW
Q_{MS} - Total reactive power supplied by the Main Source in KVAr
P_{Loss} - Active power loss in a particular branch in KW
Q_{Loss} - Reactive power loss in a particular branch in KVAr
P_D, Q_D - Active and reactive power demand in KW / KVAr respectively
$P_{DG(t)}^{min}$ - Minimum real power generated by DG unit in KW
$P_{DG(t)}^{max}$ - Maximum real power generated by DG unit in KW
TP_{Loss} - Total active power loss in KW
$P_{DG(t)}$ - Active power supplied by DG unit at node 't' in KW
V_t^{min} - Minimum Voltage at t^{th} node (0.95 p.u.)
V_t^{max} - Maximum Voltage at t^{th} node (1.05 p.u.)
V_t - Voltage at t^{th} node

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