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Optimal Placement of Distributed Generators in Radial Distribution System for Reducing the Effect of Islanding

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Abstract – The present trend of increasing the penetration levels of Distributed Generator (DG) in the distribution network has made the issue of Islanding crucial for the reliable operation of the network. The islanding, if not detected early may lead to the collapse of the system as it can drive the distribution system to the cascaded failure. In this paper, an extensive study of the effect of DG placement and sizing is performed by dividing the system into different zones to obtain a reduced effect of islanding. The siting and sizing of DG is carried out to improve the overall voltage profile or/and reduction in active power loss using two stage Genetic Algorithm (GA). In the first stage a basic knockout selection is considered and the best population is taken for next stage, where roulette selection for crossover and mutation is performed for optimal placement and sizing of DGs. The effect of the islanding, due to load variations is reduced by optimal siting and sizing of DG. The effectiveness of the proposed scheme is tested on the IEEE 33 and 69 radial bus systems and the results obtained are promising.

Keywords: Distributed generation, Penetration level, Islanding, Voltage stability, Active power loss, Genetic algorithm

1. Introduction

Distributed Generation (DG) is an electric power source connected directly to the distribution network. The various definitions and technologies are described in [1, 2]. DG plays a crucial role for the security, reliability and efficiency of the present day power system [3]. The importance of the DG units in the network is more profound with the increased emphasis on green energy technology and environmental concerns.

Various schemes using different methods have been proposed in the literature for the optimal placement of the DG units in the network for overall voltage profile or/and reduction in active power loss [4-8]. A comprehensive analysis of methods and models for optimal placement of DG units is given in [9]. The impact of DG penetration and siting has been discussed in [10]. An analysis on improvement of voltage profile, loss minimization, power transfer capability using the continuation power flow method and the impact of DG on voltage stability at sensitive buses is discussed in [11]. An approach for DG planning considering the load growth uncertainties, DG integration, the uncertainty due to volatility of fuel prices are proposed in [12, 13]. An optimal planning of dispatchable and non-dispatchable DG units for loss reduction, for optimal hourly production, power factor improvement, penetration of DG units using PSO and reduction in annual energy losses are proposed in [14, 15]. A detailed analysis of the network security [16], losses, reliability, voltage improvement [17], loadability enhancement [18, 19], withstanding capacity of the secondary distribution networks [20] in the presence of DG have been reported in literature.

According to IEEE STD 1547-2003 islanding is a situation in which a distribution system becomes electrically isolated from the remainder of the power system due to a fault upstream or any other disturbance and yet continues to be energized by the DG connected to it [21]. The islanding may occur due to internal faults in the system or due to load variations beyond the permissible limits. The islanding detection techniques are broadly classified into Active and Passive techniques [22]. Active islanding detection techniques have smaller non-detection zones (NDZ) than passive techniques. Active methods are not as simple and easy to implement as passive methods [23, 24].The passive scheme makes decisions based on the local measurements of voltage and current signals. The algorithms of this scheme include under/over frequency and voltage, rate-of-change of frequency and power, vector surge and harmonic distortion indices [25]. A comprehensive survey of islanding protection with renewable DG is reported in [26]. The proper placement of DG can aid the intentional islanding process thereby reducing the load shedding [27].

In this paper, a scheme has been proposed to reduce the effect of islanding while improving the overall voltage profile and/or minimizing the active power losses in the

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distribution system. The scheme has been implemented by dividing the system into zones and finding the optimal locations and sizes of DGs in the individual zones using GA. The conventional GA requires a large population size for an optimal solution; it has largely been reduced by a proposed two stage selection method. This method combines the process of a knockout selection and roulette wheel selection. The initial population in the first stage is made up of a vast number of locations and sizes of DGs in the individual selected zones. The roulette wheel is made of N-1 number of slots, where N is the number of buses in the second stage. The N-1 best results from the initial best results of the knockout selection are taken for roulette wheel selection and then the process of cross over and mutation are performed. By this, the best individuals with very good fitness are taken into consideration and the convergence is much faster. The proposed method is tested on IEEE-33 and IEEE-69 standard radial distribution test systems. The proposed two stage GA is able to find the best solutions, and the results obtained in reducing the effect of islanding are promising.

2. Proposed Scheme for Optimal Placement of DG

The optimal placement and sizing of DG in the network is crucial in the planning stage of any network. The appropriate placement of DG can result in several benefits like reduction of active power losses, increased reliability of the network, improved voltage profile, peak demand shaving [2].

2.1 Problem formulation

In the proposed scheme, the objective of siting and sizing of DGs to reduce the effect of islanding by considering the improvement of voltage profile and reduction of active power losses is formulated as:

$$F = (W_1 * Max[V_S]) + (W_2 * Max[P_{Losses,diff}]) \quad (1)$$

Where W_1 and $W_2$are the weights assigned to the objective with $W_1+W_2=1$.

$$V_s = \frac{\sum_{i=1}^{m} V_{i\ With\ DG} - \sum_{i=1}^{m} V_{i\ Without\ DG}}{\sum_{i=1}^{m} V_{i\ Without\ DG}} *100\% \quad (2)$$

$$P_{Losses,diff} = \left[\frac{P_{Losses} - P_{Losses,DG}}{P_{Losses}} *100\% \right] \quad (3)$$

$$P_{Losses} = \sum_{a=1}^{k} P_a \quad (4)$$

$$P_a = R_i * \frac{\{P_i^2 + Q_i^2\}}{|V_i|^2} \quad (5)$$

Where $V_{i\ Without\ DG}$ is the voltage at i^{th} bus without DG, $V_{i\ With\ DG}$ is the voltage at i^{th} bus with DG, m is the total number of buses in the system, P_{Losses} is the total active power losses in the system without DG, $P_{Losses,DG}$ is the total active power in the system with DG, P_a is the power loss in the line connecting buses a and b, k is the total number of lines in the system, R_i is the resistance of the line connecting adjacent buses, P_i is the Active power of the i^{th} bus, Q_i is the Reactive power the i^{th} bus and V_i is the voltage at i^{th} bus. The following constraints are considered for finding the optimal location and size of DGs

$$V_{\min} \le V_i \le V_{\max} \quad (6)$$

$$0 \le P_{DG} \le P_D * PL \quad (7)$$

$$\text{Penetration Level}(PL) = \frac{P_{DG}}{P_{LOAD}} *100\% \quad (8)$$

Where V_{min} is the minimum voltage at any bus, considered as 0.95 p.u. in this work and V_{max} is the maximum voltage considered as 1.05 (p.u), P_{DG} is the active power supplied by the DG at unity power factor and $P_D$is the total power demand in the network. The total penetration level of all DGs is considered to not exceed 30% of the total supply to the distribution system [11]. The optimal location and size of the DGs are obtained to reduce the effect of islanding. After placement of DGs by the proposed method there is simultaneous improvement in voltage profile and reduction in losses with the increase in load profile in individual island formed. The output of DGs is assumed to be in either UP or DOWN state without any intermediate state in between.

2.2 Genetic algorithm

The placement and sizing of DG in the system is determined using Genetic Algorithm (GA). GA derives its behaviour from a metaphor from the process of Evolution in nature [18]. The advantage of using evolutionary computational technique is the simplicity in approach, robust response to changing circumstances and its flexibility. Therefore, it has been extensively used for various issues like reduction of losses, improvement of voltage profile [29-32].

Selection is the process of choosing two parents from the population for crossing. The tournament selection strategy provides selective pressure by holding a tournament competition among N individuals. The best individual from the tournament is the one with the highest fitness, which is the winner of N. Roulette selection is one of the traditional GA selection techniques. The principle of roulette selection is a linear search through a roulette wheel with the slots in the wheel weighted in proportion to the individual's fitness values. After the selection (reproduction) process, the population is enriched with better individuals.

Crossover is the process of taking two parent solutions and producing from them a child. Mutation recovers the lost genetic materials and prevents the algorithm to be trapped in a local minimum. Elitism is the procedure by which the weakest individual of the current population is replaced by the fittest individual of the immediately preceding population.

The encoding of each parent considered for present study is given as:

DG Loc_1	DG Loc_2	……	DG Loc_n	DG Cap_1	DG Cap_2	……	DG Cap_n

Where n is the number of DGs. *DG* Loc_1 is the location of the first DG, *DG* Loc_2 is the location of the second DG and so on. *DG* Cap_1 is the capacity of the first DG; *DG* Cap_2 is the location of the second DG and so on.

3. Proposed Methodology

The values of the weights are selected depending upon the purpose of the objective function: (a) improving overall voltage profile, (b) reducing total active power losses and (c) simultaneously achieving both (a) and (b).The systems have been divided into different zones for the placement of DG. The number of zones considered for the present study depends upon the number of DGs considered, whereas the location of zones is considered arbitrarily with each zone having one DG.

3.1 Division of the system into different zones

3.1.1 33 Bus System

The test system has been analysed for 3 DGs and 4 DGs respectively. For this purpose the system is divided into different zones and the placement of DG is performed.

1) 3 DGs
Zone 1: Bus 2 to Bus 18
Zone 2: Bus 19 to Bus 25
Zone 3: Bus 26 to Bus 33.

2) 4 DGs
Zone 1: Bus 2 to Bus 18
Zone 2: Bus 19 to Bus 22
Zone 3: Bus 23 to Bus 25
Zone 4: Bus 26 to Bus 33.

3.1.2 69 Bus System

The bus system has been analysed for 4 DGs, 5 DGs and 6DGs respectively after dividing the system into different zones.

1) 4 DGs
Zone 1: Bus 3 to Bus 27, Bus 47 to Bus52 and Bus 66 to Bus 69
Zone 2: Bus 28 to Bus 35
Zone 3: Bus 36 to Bus 46
Zone 4: Bus 53 to Bus 65.

2) 5 DGs
Zone 1: Bus 3 to Bus 27 and Bus 66 to Bus 69
Zone 2: Bus 28 to Bus 35
Zone 3: Bus 36 to Bus 46
Zone 4: Bus 47 to Bus 52
Zone 5: Bus 53 to Bus 65.

3) 6 DGs
Zone 1: Bus 3 to Bus 27
Zone 2: Bus 28 to Bus 35
Zone 3: Bus 36 to Bus 46
Zone 4: Bus 47 to Bus 52
Zone 5: Bus 53 to Bus 65
Zone 6: Bus 66 to Bus 69.

3.2 Proposed algorithm

The various steps in implementing the proposed two stage selection scheme for placing and sizing of the DGs is summarized as:

i. Read the system data
ii. Initially a vast population size of 500 DGs of different locations and sizes are considered randomly for each zone.
iii. The fitness of the objective is checked for each value and the population is ranked according to the best results arrived for each zone.
iv. The top ranked population of each zone equal to the Number of buses (N) -1 is selected for the next stage.
v. A roulette wheel selection is followed for the crossover and mutation process. Two point crossover is performed with mutation rate as 6%.
vi. The off springs of step v become the parents for the next generation and step v is repeated until the convergence is achieved or the maximum generation is reached.

After placement of DGs, the loads of all the buses are increased from base case to 125% of base load. The load at which islanding occurs is identified along with the vulnerable bus.

4. Simulation Results

All simulations are performed in MATLAB 7.10. [33] and PSAT [34]. Three different cases are considered as: case 1 is when W_1=1 (for voltage stability maximization), case 2 when W_1 and W_2 are varied between 0 and 1 for improving voltage profile and reducing active power loss simultaneously, case 3 is when W_2=1 (for loss minimization). In the present study for case 2, the values of W_1 is taken as 0.25 for 33 bus system and as 0.75 for 69 bus system

Table 1. Comparison of results for 33 bus with 3 DGs

Case	Minimum voltage in the system (p.u)	Voltage stability improvement (%)	Total active power loss (MW)	Reduction in active power loss (%)	Islanded bus
Without DG	0.9131	-	0.1968	-	-
Case1	0.9816	4.32	0.03895	80.26	4
Case2	0.9813	4.31	0.03732	81.03	4
Case3	0.9803	4.28	0.03735	81.11	4
Existing method [6]	-	4.32	0.0423	78.51	3

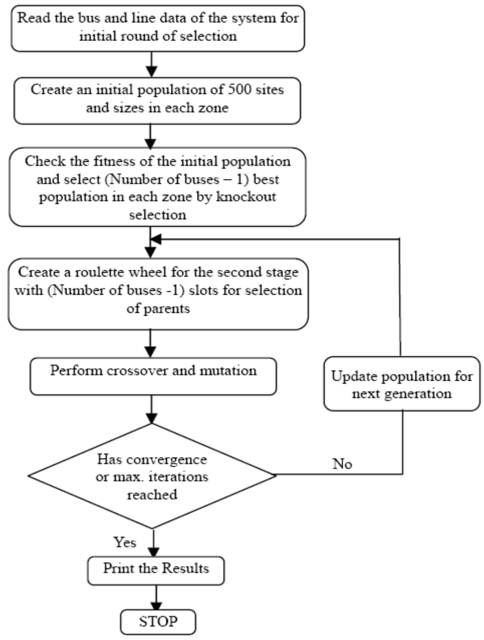

Fig. 1. Flowchart for optimal siting and sizing of DG

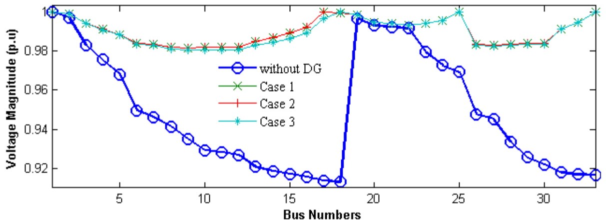

Fig. 2. Comparison of Voltage Profiles of 33 Bus System with 3 DGs and without DG

respectively. After simulating various combinations, the selected values are found to be giving better results. The results obtained from the proposed scheme are presented.

4.1 33 Bus system with 3 DGs

The optimal location of DGs obtained from the proposed scheme is at bus numbers 17, 25 and 33 with ratings as 450kW, 380kW, 275kW respectively when W_1 is considered as 1. When W_1 is taken as 0, the optimal location of DGs obtained are at bus number 18, 25 and 33 with ratings as 444kW, 384kW and 273kW respectively. However, when W_1 is taken as 0.25 the optimal locations of DGs are found to be same as case 1(W_1 = 1) but the ratings of each DG are 450kW, 387kW, 275 kW respectively. It has been observed that the system gets islanded for an overload of 15.25% at bus 4 forming a main system consisting of buses 1-3,19-22,23-25 and an islanded system consisting of buses 4-18,26-33. However, since the DGs are connected in this island therefore they supply active power reducing the impact of islanding.

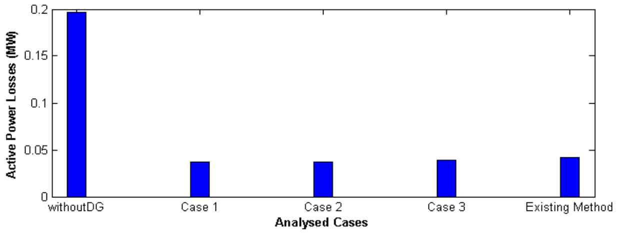

Fig. 3. Comparison of real power losses of 33 bus system with 3 DGs

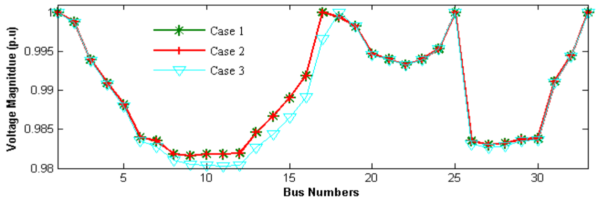

Fig. 4. Comparison of voltage profiles of 33 bus system with effect of DG for different weights

From Fig. 2 it is found that when W_1 is taken as 1 or 0.25, the overall improvement in voltage stability is almost the same. The minimum voltage in the system is also much improved than when compared in the absence of DG. From Fig. 3 it is found that when W_1 is taken as 0, there is marginal improvement in the reduction of losses. It is better to consider case 2 as the best since, it offers a better solution with respect to both voltage stability improvement and reduction in losses. An analysis of all the scenarios is presented in Table 1. From the table, it can be seen that the placement of DG for a multiple objective function gives almost the same result as that of a single objective function. So, it is much beneficial to consider multiple objectives for optimal placement and sizing of DG. The effect of weights on voltage profiles after DG placement in the system can be seen in Fig. 4.

4.2 33 bus system with 4 DGs

For this case when 4 DGs are considered in the system

Table 2. Comparison of results for 33 bus with 4 DGs

Case	Minimum voltage in the system (p.u)	Voltage stability improvement (%)	Total active power loss (MW)	Reduction in active power loss (%)	Islanded bus
Without DG	0.9131	-	0.1968	-	-
Case1	0.9814	4.42	0.03753	82.97	4
Case2	0.9813	4.36	0.03885	83.43	4
Case3	0.9803	4.29	0.03886	83.73	4

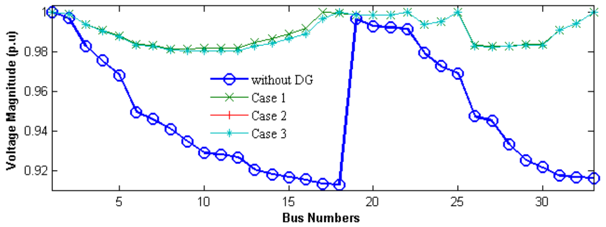

Fig. 5. Comparison of Voltage profiles of 33 bus system with 4 DGs

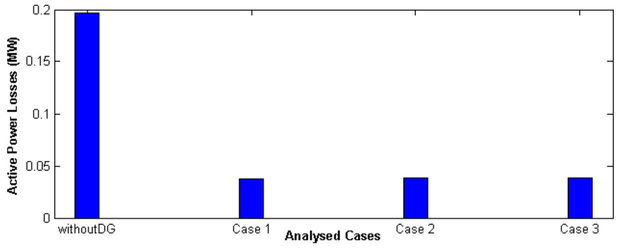

Fig. 6. Comparison of real power losses of 33 bus system with 4 DGs

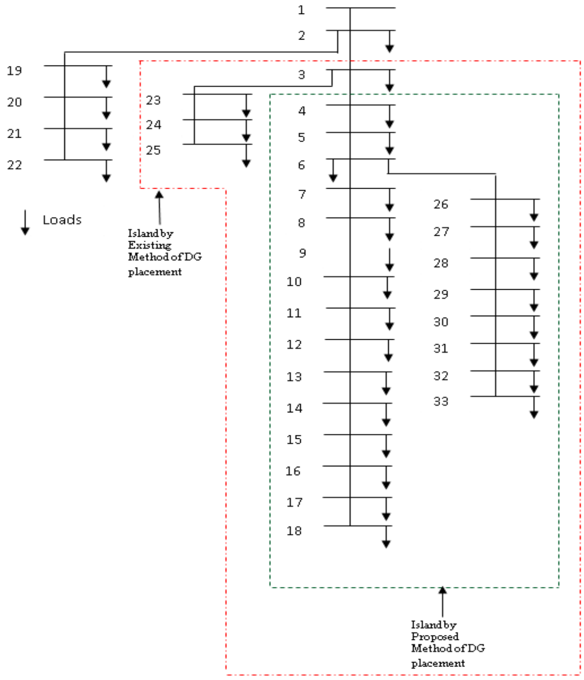

Fig. 7. Formation of Island in 33 Bus System by existing [6] and proposed method of DG placement

the optimal location of DGs obtained are at bus numbers 17, 22, 25 and 33 with ratings as 450kW, 100kW, 120kW, 263kW respectively for W_1 =1. When W_1 is considered as 0.25 or 0 the optimal locations of DGs are at buses 18, 22, 25 and 33. The ratings of DG obtained are 450kW, 98kW, 120kW and 272kW respectively when W_1 is taken as 0.25. When W_1 is taken as 0, the ratings of DGs obtained are 447kW, 100kW, 120 kW, 274kW respectively. The system gets islanded at bus 4 for an overload of 15.25% forming a main system consisting of buses 1-3,19-22,23-25 and an islanded system consisting of buses 4-18, 26-33. Since the DGs are connected in the islanded network thus they supplies active power in the islanded system and thereby reduces the impact of islanding.

From Fig. 5 and Fig. 6, it can be seen that, when DG is placed for simultaneously improving the voltage profile and reducing the losses, it gives a better result. An analysis of the scenarios is presented in Table 2. From the table it can be seen that the results are much better while considering multiple objective functions rather than a single objective function. However, in all the above cases, the reduction in losses and improvement in voltage stability with the addition of the 4 DG is very marginal. Hence it would be much beneficial to divide the system into 3 zones and place 3 DGs to reduce the cost due to placement of DG. The results have been compared with existing method [6]. The Fig. 6 shows the islands by the proposed method and existing method. It is observed that in existing method the islanding occurs at bus 3 for same operating conditions. The existing method of DG placement creates an island where the number of loads connected to the DGs are more. Thus the stress on the DGs in the island is reduced by proposed two stage GA algorithm.

4.3 69 Bus System with 4 DGs

For the given scenario the optimal locations of DGs obtained are at bus numbers 67, 35, 46 and 64 with capacities as 472kW, 25kW, 49kW and 444kW respectively for W_1 =1. When W_2 is considered as 1 or 0.75 the optimal locations of DGs obtained are 67, 35, 45 and 64. However when W_1 is considered as 0.75 the DG sizes obtained are 422kW, 27kW, 53 kW and 469 kW respectively. But for W_2 = 1 the ratings of DGs obtained are 439kW, 25kW, 51kW and 475kW respectively. The system gets islanded at bus 10 for an overload of 13.35% forming a main system consisting of buses 1-9, 28-65 and an islanded system consisting of buses 10-27, 65-69. The DG presence in the islanded network reduces the impact of islanding.

Table 3. Comparison of results for 69 bus with 4 DGs

Case	Minimum Voltage in the system (p.u)	Voltage stability improvement (%)	Total Active Power Loss (MW)	Reduction in Active Power Loss (%)	Islanded bus
Without DG	0.9104	-	0.2056	-	-
Case1	0.9874	2.41	0.03346	85.79	10
Case2	0.9871	2.38	0.03286	86.23	10
Case3	0.9864	2.31	0.03275	86.84	10

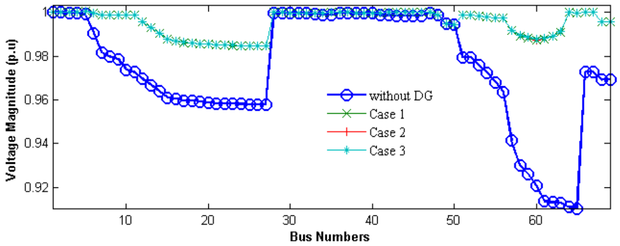

Fig. 8. Comparison of voltage profiles of 69 bus system with 4 DGs

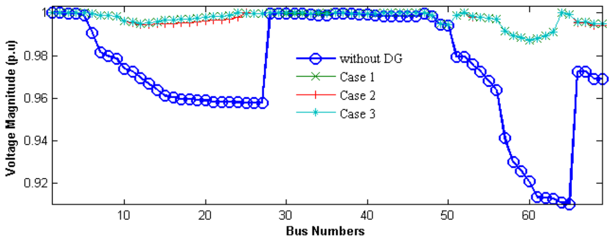

Fig. 10. Comparison of Voltage Profiles of 69 Bus system with 5 DGs

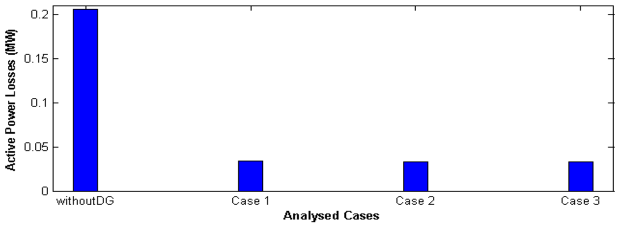

Fig. 9. Comparison of real power losses of 69 bus system with 4 DGs

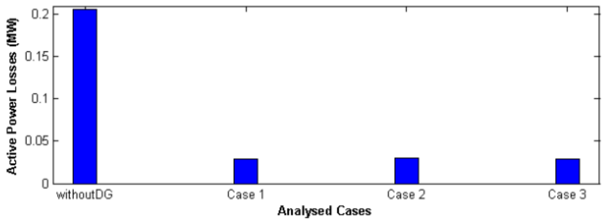

Fig. 11. Comparison of real power losses of 69 bus system with 5 DGs

Table 4. Comparison of results for 69 bus with 5 DGs

Case	Minimum Voltage in the system (p.u)	Voltage stability improvement (%)	Total Active Power Loss (MW)	Reduction in Active Power Loss (%)	Islanded bus
Without DG	0.9104	-	0.2056	-	-
Case1	0.9874	2.41	0.03017	85.33	56
Case2	0.9870	2.38	0.02935	85.72	56
Case3	0.9865	2.35	0.02930	87.73	56

An analysis of the scenarios is presented in Table 3. From, the table it can be observed that, when a single objective is considered for reducing the losses, the results are much better.

From Fig. 8 it can be seen that, the voltage stability margin improves when W_1 is not taken as zero. From Fig. 9 it is shown that the losses are reduced appreciably when W_2 is taken as 1.

4.4 69 Bus System with 5 DGs

The optimal locations of DGs obtained from the proposed scheme are at bus numbers 24,35,45,52 and 64 with ratings as 200kW, 25kW, 50kW, 240kW and 460kW respectively when W_1 is considered as 1. When W_2 is considered as 1 the optimal locations of DGs obtained are 24, 34, 45, 52 and 64 with ratings as 230kW, 25kW, 51kW, 233kW and 459kW respectively. However, When W_1 is considered as 0.75 the optimal locations of DGs obtained are 25,34,45,52 and 64 with ratings as 212kW, 25kW, 51kW, 227kW and 465kW respectively. The system gets islanded at bus 56 for an overload of 13.35% forming a main system consisting of buses 1-55, 65-69 and an islanded system consisting of buses 56-65. The DG presence at bus 64 reduces the impact of islanding.

From Figs. 10 & 11, it is clear that the minimum voltage in the system is increased and there is appreciable reduction in active power losses when the DGs are placed simultaneously for voltage profile improvement and loss reduction. An analysis of the scenarios is presented in Table 4. From the table, it can be seen that, when multiple objectives are considered, the loss reduction is more and the minimum voltage in the system also improves a lot.

4.5 69 Bus System with 6 DGs

The optimal locations of DGs obtained for this case are 24, 34,45,52,64 and 69 for all combinations of weights. But

Table 5. Comparison of results for 69 bus with 6 DGs

Case	Minimum Voltage in the system (p.u)	Voltage stability improvement (%)	Total Active Power Loss (MW)	Reduction in Active Power Loss (%)	Islanded bus
Without DG	0.9104	-z	0.2056	-	-
Case1	0.9880	2.48	0.02716	86.79	56
Case2	0.9879	2.47	0.02634	87.19	57
Case3	0.9877	2.45	0.02614	87.29	57
Existing Method [6]	-	-	0.0280	86.38	6

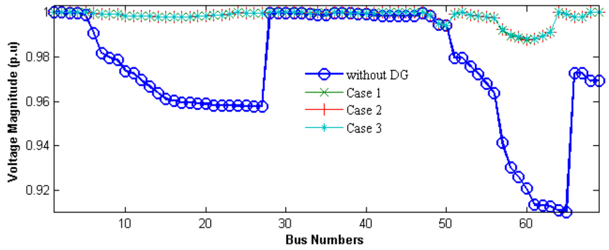

Fig. 12. Comparison of Voltage Profiles of 69 Bus System with 6 DGs and without DG

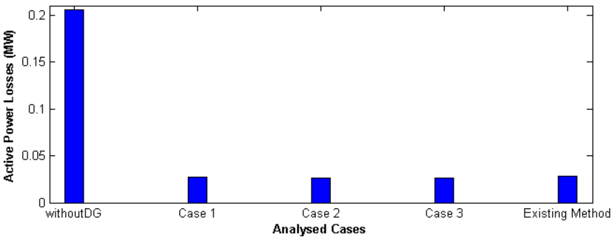

Fig. 13. Comparison of real power losses of 69 bus system with 6 DGs

different capacities are obtained for various combinations of weights as follows: (i) When W_1 is considered as 1 the ratings are 188kW, 25kW, 50kW, 236kW, 463kW and 25kW respectively. (ii) When W_2 is taken as 1 the ratings of DGs obtained are as 204kW, 25kW, 51kW, 237kW, 513kW and 26kW respectively. (iii) When W_1 is considered as 0.75 the ratings of DGs obtained are 204kW, 25kW, 51kW, 237kW, 513kW and 26kW respectively. When W_1= 1, the system gets islanded at bus 56 for an overload of 15.25% forming a main system consisting of buses 1-55, 65-69 and an islanded system consisting of buses 56-65. In the remaining cases, the system gets islanded at bus 57 for an overload of 13.35% forming a main system consisting of buses 1-56, 65-69 and an islanded system consisting of buses 57-65. Since the DGs are connected in the islanded network in both the cases thus it supply the active power in the island.

From Fig. 12, the voltage stability margin is improved when W_1 is considered as 0.75. The losses are marginally reduced when W_2 is considered as 1 than when considered as 0.25, which can be seen from Fig. 13. An analysis of the scenarios is presented in Table 5. It is evident from the table that, even though losses are greatly reduced by considering a single objective function, by considering

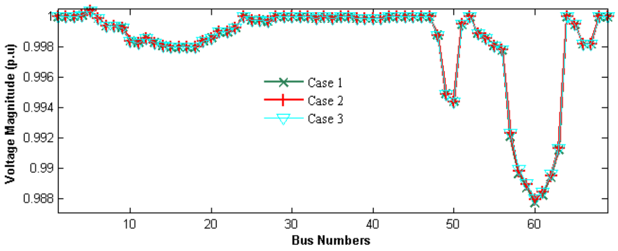

Fig. 14. Comparison of voltage profiles of 69 bus system with effect of DG for different weights

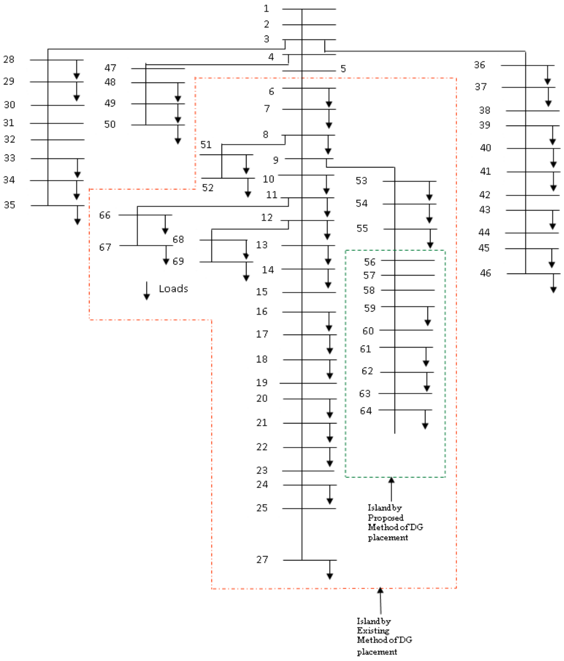

Fig. 15. Formation of Island in 69 Bus System by existing [6] and proposed method of DG placement

different weights for W_1 and W_2 the loss reduction is also appreciable with very good improvement in voltage stability margin.

The losses are appreciably reduced with the placement of the 6th DG in the system. With the increase in number of DGs the overall penetration of the DGs is reduced and the number of buses in the island is greatly reduced thereby increasing the number of buses connected to the grid.

The results have been compared with the existing method [6]. The Fig. 13 shows the formation of islands by the proposed method and existing method. It is seen that in existing method the islanding occurs at bus 6 for same operating conditions. The existing method of DG placement increases the stress on the DG by connecting more loads to the DGs. The proposed two stage GA algorithm reduces the stress on the DGs in the island. Fig. 14 shows the effect of weights on voltage profiles after DG placement in the 69 bus system.

5. Conclusions

In this paper, a two stage GA based optimal siting and sizing of DG is proposed to reduce the effect of islanding by simultaneously improving the overall voltage profile and reducing the total active power loss in individual island. The system is divided into zones for reducing the search space for optimal siting and sizing of DG in the system. The division of systems into zones allows the placement of smaller capacity DGs throughout the system rather than a single DG of larger capacity. In a two stage GA based optimization, at first stage, the weaker solutions are neglected and the fitter values are taken for the crossover and mutation in the second stage. This results in better quality of solutions and faster convergence of the results. Moreover, the allocation of DG based on the zones is much effective than opening the entire search space for the allocation of DG in the network.

However, in the event of unstable islands due to power mismatch in any island, proper control measures have to be implemented to maintain system stability.

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