The New Approach for Optimal Siting and Sizing of Multiple Distributed Generators using NSGA II

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Abstract: *After the digital revolution, every customer in power system requires a reliable and quality power, even though it costs more. But, the dependency on fossil fuels is the major threat against the sustainable development of any developing country. Recently, the Distributed Generation (DG) with renewable energy sources creates an emerging way of fulfilling challenges and also provides vast opportunities in power generation, by evolving various novel technologies. Even though, the DGs are used to reduce system losses and increase voltage level, the inapt size and incorrect spot of DGs steer to higher power losses and appalling voltage levels. Therefore, this proposed work aims to explore the optimal locations and capacities of DG units, by using Final Node Voltage Discrepancy Factor (FNVDF) and NSGA II, respectively. The objectives of this work are to diminish the power losses and to get better voltage profile. The execution of this algorithm is illustrated in 33 and 69 bus radial distribution test systems and the results are compared with the results of GA. This proposed method proves its efficiency and hence, it encourages the new dimension of power system with increased volume of renewable energy sources.*

Key words: *Distributed Generation, Final Node Voltage Discrepancy Factor, NSGA II, Radial Distribution Network.*

1. Introduction

Sustainability is defined as, the practice of maintaining productivity indefinitely, by replenishing resources without degrading or endangering natural biotic systems. The sustainable development is defined as, the development that meets the present needs without compromising the ability of future generations to meet their own needs [1]. Fulfilling the energy requirements expertise play a crucial role in socio-economic escalation of any country. Besides the well-being effects of energy technologies, they are also causing several adverse effects such as, environmental contamination and degradation. It is obvious that the continuation of fossil fuels dependence for energy necessity is the major reason for pollution and climate change. The exploration of sustainable substitutes for upcoming energy need becomes progressively more essential due to deteriorating energy resources. Under this crucial situation, the Distributed Generation (DG) is intended to settle down this setback in power industry. According to the Institute of Electrical and Electronic Engineers (IEEE), the definition for DG is given as; it is pretty smaller power facilities and also to be connected within the distribution network. It is predicted that the dispersion level of DGs will cover 25% of the worldwide total demand in next 10 years [2].

The connection of DG units in distribution network induces several positive benefits as, improvement in voltage profile, power quality and reduction in system losses. The prominent harmful impact is the increase in short circuit level and thereby, disturbing the relay coordination in the existing protective system. Since, these impacts depend on type, capacity and place of the resources, the decision of optimal location and capacity of DGs are the most significant things. The category of DG is classified depending upon its structure and technology [3]. It is reported that the proper DG installation at appropriate location can improve the power quality of electrical network [4]. Furthermore, the advantages of DGs are listed as, small sizes, easy finding of sites, less construction time and low investment cost [5]. Several methods are listed for the solution of optimal DG placement problem and these are categorized such as, analytical methods, numerical methods and heuristic methods [6-8].

The analytical approach is discussed for the optimal placement of DG units, but only with unity power factor [9]. The exact size of DG units is ascertained, by using three different types of PSOs namely, traditional PSO, Evolutionary PSO (EPSO) and Rank Evolutionary PSO (REPSO) [10]. Even though, these algorithms are proficient in giving superior solutions, they neglect their attention towards the optimal location of DG units. Artificial Bee Colony (ABC) algorithm is used to determine the optimal size and location of DG unit, by minimizing the total system real power loss without considering the voltage deviation [11]. A hybrid algorithm i.e. GA combined with PSO, is presented for solving the problem of optimal location and sizing of DG in distribution systems [12].

A simple, but conventional iterative search technique is combined with Newton – Raphson load flow for finding the optimal placement of DG [13]. However, the objective is to find the optimal location for DG, but not considering the DG size. An innovative method is experimented for finding the correct size and place of DG units, by supporting the intended islanding procedure to strengthen the static stability of recently formed islands [14]. The simultaneous placement of DG and capacitor in radial distribution network is studied with different load levels [15]. A new-fangled framework is projected to obtain the optimal placement and size of PV units in campus area environment, by combining the Geographical Information Systems (GIS) with mathematical optimization and simulation components [16].

A new algorithm is proposed for optimal allocation and capacity of DG in distribution system based on Power Stability Index (PSI) [17]. But, that approach is applied without considering the system losses and also it requires a strong analytical skill to visualize the impact of DG on voltage profile and voltage stability. Hence, this research attempt proposes a novel indicator, Final Node Voltage Discrepancy Factor to determine the optimal locations of multiple DG units. NSGA II based optimization is used for determining the optimal sizes of multiple DGs. It is achieved with the objectives of minimizing the total real power losses and improvement of the voltage profile, but maintains system operation and security constraints in radial distribution system. The results that are achieved from this proposed methodology are compared with the available literature and prove to be encouraging.

The organization of this paper is as follows. Section 2, addresses the approach to find the optimal locations for DGs, by having a load flow for radial distribution system and the calculation of Final Node Voltage Discrepancy Factor (FNVDF). The problem formulation and NSGA II algorithm are elaborated in sections 3 and 4, respectively. The simulation results in test systems are illustrated in section 5 and some of the important conclusions are presented in section 6.

2. Finding of the optimal locations for DGs

The valid benefits of DGs are only feasible, if they are correctly located with exact size. Otherwise, they induce higher power losses and shocking voltage reductions in the system. Therefore, the need of discovering the correct locations for DGs is perceptibly imperative in this work.

2.1 Load flow analysis for a radial distribution system

Conventional load flow analysis such as, Newton Raphson (NR) and Gauss Seidel (GS) methods may become incompetent for the analysis of distribution

systems. Because, they have some distinct characteristics like, radial structure, higher value for R/X ratio and unstable dispersed loads [18]. Due to these unique characteristics of distribution systems, the power flow computation of distribution system necessitates a diverse approach, even though it is somewhat tricky as compared to the transmission systems. There are numerous sophisticated methods available to perform the load flow analysis of both balanced and uneven radial distribution systems and they can be broadly separated into two categories [19].

The first category covers the methods, in which suitable modifications can be incorporated in the existing load flow schemes such as, NR and GS methods. Subsequently, the second cluster of methods is derived from equivalent current injection and forward-backward sweep algorithms by using both the Kirchhoff's laws. Because of its lower memory requirements, less computational time and efficient convergence characteristics, the second category of methods have earned a significant volume of esteem in the load flow analysis of distribution systems [18-19]. The analysis of distribution systems is the most important activity, since the distribution systems act as the final link between the bulk power system and the consumers.

In this contemporary investigation, forward-backward sweep algorithm is adopted to observe the load flow solution of balanced radial distribution system. This method avoids the repetitive computations at each branch and makes this approach as computationally effortless and competent.

2.2 Computation of Final Node Voltage Discrepancy Factor (FNVDF)

The customer strength in the system is remained original, if and only if, the operating parameters are well maintained within their permissible limits and the improved quality of power is delivered to them. The voltage level at the end nodes of a distribution system is always comparatively dropping in nature than the other nodes in the system [20]. So as to maintain this dropping voltage level as original, a solution is prescribed in this research, by finding the proper placement of DG units. In order to discover the opt location for placing DG units, a new index called, Final Node Voltage Discrepancy Factor (FNVDF) is proposed in this study [21].

In order to confine the search space to only some buses, tail end nodes are identified directly from the network structure of distribution network. The Final Node Voltage Discrepancy Factor (FNVDF) is calculated using Eq. (1), by piercing DG with 50% of the total feeder demand at each node. When, DG is connected at bus i, FNVDF for bus i, is given as:

$$\text{FNVDF}_i = \sum_{m=1}^{NTEN} \frac{(V_{nominal} - V_m)^2}{NTEN} \qquad (1)$$

FNVDFi gives the total deviation of voltages of

all tail end nodes of the network with respect to the rated voltage. The optimal location of DG in the distribution system is identified as the bus, which has the minimum FNVDF value when DG is inserted.

3. Problem formulation

It is well known that the losses in distribution system are always higher than the transmission system. Therefore, there is a need to explore the correct placement and size of the DG units, which are connected in distribution system. Because, the opt location and size of DG units certainly reduces the power losses and diminishes the deviation in bus voltages of given radial distribution system.

3.1 Objective function

Two objective functions are considered in this research i.e., one is for losses and another one is for voltage profile. They are considered as two separate single objectives. The minimization of real power losses is used as first objective. The real power losses in the system is given by Eq. (2),

$$f_1 = P_{loss}$$
(2)

Improvement of voltage profile such as reducing the voltage deviation from its nominal value is considered as second objective. The objective function, which is used to minimize the voltage deviation is given by Eq. (3),

$$f_2 = \sum_{i=1}^{n}[V_{nominal} - V_i]^2$$
(3)

Hence, the fitness function of this exploration is taken as the minimization of real power losses and voltage deviation of all the buses in the test system. In order to handle these multi objectives, the NSGA II based optimisation approach is selected for this research.

3.2 System Constraints

The chance of getting accurate results from of any optimization problem is depending upon the consideration of all influencing parameters as constraints. The constraints available in this problem are identified and listed as follows.

Bus voltage limit:

$$V_i^{min} < V_i < V_i^{max}$$
(4)

Real and reactive power limit:

$$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max}$$
(5)

$$Q_{gi}^{min} \leq Q_{gi} \leq Q_{gi}^{max}$$
(6)

Power balance constraint:

$$\sum_{i}^{ng} P_{gi} = \sum_{i}^{nl} P_{Di} + P_{loss}$$
(7)

3.3 Constraints Handling

The voltage constraint $(V_{constraint})$ is initialized as 0, then the constraint of bus voltage limit in Eq. (4) can be rewritten as follows,

$$if \ V > V_{min} \ \& \ V < V_{max}$$
$$V_{constarint} = 0$$
$$else$$
$$V_{constarint} = 50$$

Finally, add the $V_{constraint}$ with first objective function,

$$fit = f_1 + V_{constraint}$$

The violated solutions are normally left out, because the formulated problem in this approach is the minimization problem. This same way of constraint handling is applied for all the remaining constraints.

4. NSGA II

The NSGA II, is the modified version of Genetic Algorithm (GA). GA is the well-known unconstrained optimization method, which manipulates all the multi objectives, by making as single objective with weighting factors. But, NSGA II is able to handle the multi objectives as they are and also gives better results than GA. Both the algorithms replicate the natural processes that allow the succeeding generations in a population to become accustomed to their surroundings. They work with a population of solutions and create new generation of solutions, until getting a global solution, by using appropriate genetic operators [23]. The steps involved in this optimization problem are depicted in a flowchart as drawn in Fig. 1.
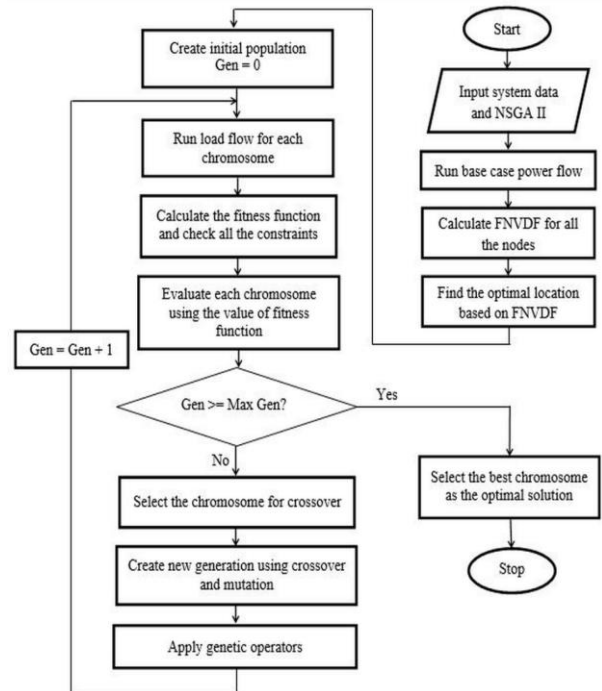

Fig. 1. Flowchart of the proposed work

The implementation of fitness function in NSGA II, plays a foremost responsibility and generally expressed in terms of objective function. Usually, the objective function is framed by considering the nature of the problem is to be optimized and the fitness function is defined as the inverse of objective function.

The NSGA II has many advantages as listed below. It solves the optimization problems with reduced computational complexity and requires no knowledge of gradient information about the response surface. NSGA II is very resistant to finish with local optima and this special feature of NSGA II makes it more suitable for a wide variety of optimization problems in all fields of engineering [24]. Due to these unique features, NSGA II becomes predominantly suitable for the problem proposed here. While, selecting the parameters of NSGA II, a special attention is paid to ensure the effectiveness of this algorithm [25] and the selected parameters are tabulated in Table 1.

Table. 1

The parameters of NSGA II

Parameters	Values
Population size	100
Crossover probability	0.9
Mutation probability	0.2
Genetic operators probability	0.2
Maximum number of generations	2000

5. Results and discussion

To examine the practicability and effectiveness of this projected technique, the simulation tests are performed in 33 and 69 bus radial distribution test systems and their single line diagrams, which are depicted in Figure 2 and Figure 3, respectively. The necessary codes are developed in Matlab 2012 with Intel core I3 processor and 4 GB RAM.
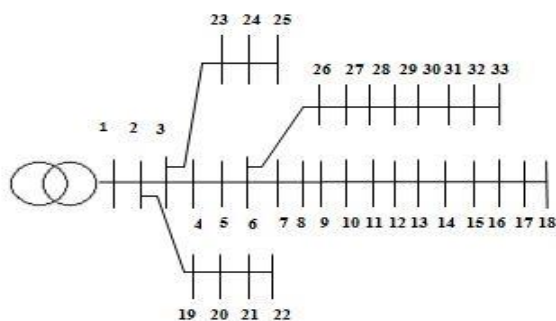

Fig. 2. Single line diagram of 33 bus radial distribution System
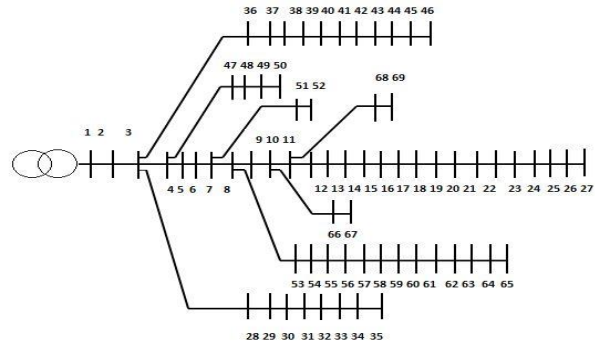

Fig. 3. Single line diagram of 69 bus radial distribution system

In order to ensure the accurateness of this projected approach, the following assumptions are followed in this methodology.

• The inferior and superior boundaries for bus voltages are fixed as 0.95 and 1.05 p.u., respectively.
• The maximum numbers of DG units assumed here are 3.
• The minimum and maximum value of DGs are limited between 100 - 600 KW, respectively for case I and case II.
• The minimum and maximum value of DGs are limited between 100 - 1000 KW, respectively for case III.

At the outset, base case load flow is performed and the corresponding values of power flows, bus voltages and line losses of both the test systems are observed. The tail end nodes for both the test systems are identified directly from the network structure and they are listed in Table 2.

Table. 2

Tail End Nodes

Tail End Nodes	1	2	3	4	5	6	7	8
33 bus system	18	22	25	33	-	-	-	-
69 bus system	27	35	46	50	52	65	67	69

The Final Node Voltage Discrepancy Factor (FNVDF) is calculated for each node, using the Eq. (1), as explained in chapter 2.2 for both 33 and 69 bus test systems. All the calculated FNVDF values are arranged in ascending manner. The bus corresponding to the minimum FNVDF value is identified as optimal location of DG in the distribution system. Hence, among all the calculated FNVDF values, the lowest three FNVDF values are considered and their corresponding buses are identified as optimal locations for placing multiple DGs. The suitable locations and their corresponding FNVDF values are tabulated in Table 3. In 33 bus system, three optimal locations for DG placement are identified as buses 9, 10, and 11. Similarly, for

69 bus system three optimal locations are derived as buses 64, 65, and 63. After finding these optimal locations, the efforts are focused towards the finding of optimal capacity of DGs to be connected in these preferred locations with the help of NSGA II based optimization algorithm.

Table. 3.

FNVDF values and potential places for DG placement

Sl. No.	33 Bus system		69 Bus system	
	Bus No.	FNVDF	Bus No.	FNVDF
1	9	0.0008575	64	0.0001661
2	10	0.0008576	65	0.0001686
3	11	0.0008823	63	0.0001831

DGs are inserted at these selected best locations in such a way that the size of the DG is varied from minimum to maximum value. For both the test systems, the size of the DGs is varied from their minimum and maximum limits. The sizes, which provide the minimum real power losses, are the best size of DGs to be placed at these optimal locations. The success of any algorithm or optimization is endorsed, only if it is suitable for a variety of situations. Here, to examine the success and stiffness of this approach three cases are considered for both the test systems as follows.

- Case I - Two DG units placement at top two locations
- Case II - Three DG units placement at all identified locations

5.1 Case I - Two DG units placement at top two locations

This case covers the placement of 2 DG units at top two identified locations. For 33 bus test system the DG units are placed at buses 9 and 10. The correct capacities of DG units in these locations are identified as 598 and 600 KW, respectively. The value of real power losses for this case is observed as 121.901 KW and the deviation in voltage has reduced to 0.0007 p.u. from 0.0025 p.u. For 69 bus test system the DG units are placed at bus numbers 64 and 65. The optimal capacities of DG units in these locations are identified as 550 and 590 KW, respectively. The value of real power losses for this case is observed as 105.518 KW and the voltage deviation has reduced to 0.0332 p.u. from 0.0965 p.u.

5.2 Case II - Three DG units placement at all identified locations

The placement of 3 DG units at all the identified locations comes under this case. For 33 bus test system the DG units are placed at all three identified buses 9, 10 and 11. The optimal capacities of DG units in these locations are optimized as 600, 440 and 511 KW, respectively. The value of real power losses for this case is observed as 116.264 KW and the voltage deviation has reduced to 0.0003 p.u. from 0.0007 p.u. For 69 bus test system the DG units are placed at all the three identified buses 64, 65 and 63. The correct capacities of DG units in these locations are observed as 600, 470 and 600 KW, respectively. The value of real power losses for this case is observed as 88.981 KW and the voltage deviation has reduced to 0.0204 p.u from 0.0332 p.u. The summary of results derived from these two cases for both the test systems is tabulated in Table 4.

Table. 4

Summary of results derived for 33 and 69 bus systems

Output parameters	For 33 bus system		For 69 bus system	
	2 DG units	3 DG units	2 DG units	3 DG units
Optimal locations	9, 10	9, 10, 11	64, 65	64, 65, 63
Optimal size (KW)	598, 600	600, 440, 511	550, 590	600, 470, 600
Real power losses (KW)	121.90	116.26	105.51	88.98
Voltage deviation (p.u.)	0.0007	0.0003	0.0332	0.0204

It is clearly evident from Table 4, as the number of DG units becomes more; the loss reduction gets increased. Hence, the total real power losses gets reduced significantly, after the placement of three DG units. At the same time, it is also ensured that all power and voltage constraints are satisfied.

The results of the above two cases, which are arrived by NSGA II based optimization algorithm, are compared with the results arrived by GA [21] and listed in Table 5. It is evident from these comparison tables that the proposed approach with NSGA II gives better results than GA. The results presented in columns 2, 4, 6 and 8 of Table 5 are obtained by employing NSGA II algorithm and considering multi objectives such as losses and voltage deviation individually. But, the results presented in columns 3, 5, 7 and 9 of Table 5 are obtained by employing GA and considering two objectives as single objective with the appropriate weighting factors.

Table.5
Comparison of results: NSGA II Vs. GA

Output parameters	Case I				Case II			
	For 33 bus system		For 69 bus system		For 33 bus system		For 69 bus system	
	NSGA II	GA	NSGA II	GA	NSGA II	GA	NSGA II	GA
Real power losses without a DG unit	209.913	209.913	209.913	209.913	224.488	224.488	224.488	224.488
Real power losses with 2 DG units	121.901	123.903	121.901	123.903	105.518	109.234	105.518	109.234
Reduction in Real power losses (KW)	88.012	86.01	88.012	86.01	118.97	115.254	118.97	115.254
% Reduction in Real power losses	41.93	40.97	41.93	40.97	52.99	51.34	52.99	51.34
Voltage deviation without a DG unit	0.0025	0.0025	0.0025	0.0025	0.0965	0.0965	0.0965	0.0965
Voltage deviation with 2 DG units	0.0007	-	0.0007	-	0.0332	-	0.0332	-

It is clearly evident from Table 5, the value of real power losses with 2 DG units are 121.901 and 105.518KW for 33 and 69 bus systems, respectively, if NSGA II based multi objective optimization method is employed. The same with GA based optimization method are 123.903 and 109.234 KW for 33 and 69 bus systems, respectively. It is also clearly evident from Table 5, the value of real power losses with 3 DG units are 116.264 and 88.981 KW for 33 and 69 bus systems, respectively with NSGA II. The same with GA are 118.831 and 89.073 KW for 33 and 69 bus systems, respectively. NSGA II outperforms GA in this proposed approach, since the reduction in losses and voltage deviation is phenomenal.
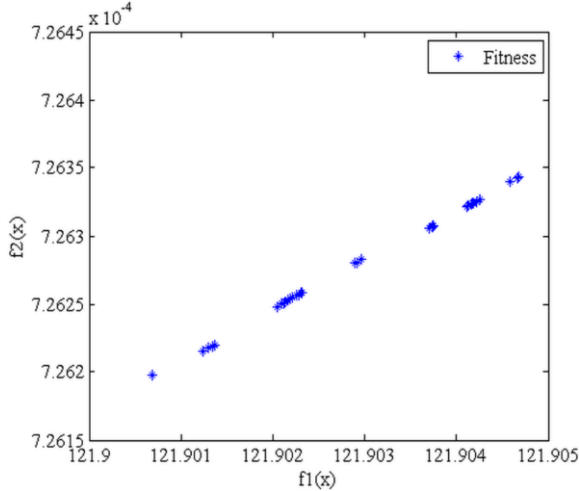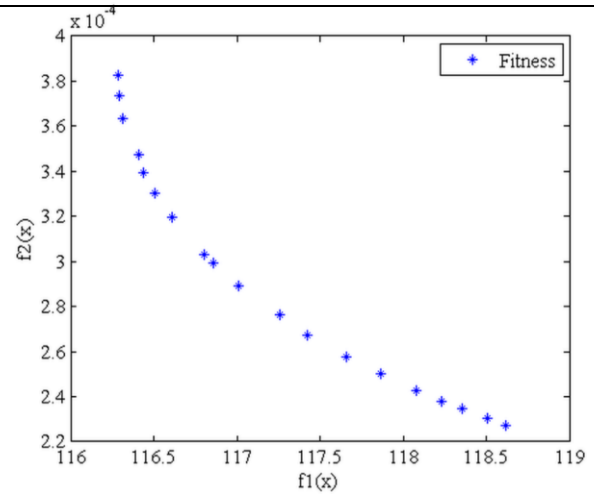

Figure 4. b). For the placement of 3 DGs
Figure 4. Fitness curve for 33 bus system

Figure 4. a). For the placement of 2 DGs

The convergence characteristics are shown in Figure 4 and Figure 5, correspondingly for 33 bus and 69 bus systems. The Figures 4 and 5 are plotted against the first objective function as mentioned in Eq. (1) and second objective function as mentioned in Eq. (2). Here the fitness function is to minimize the losses and voltage deviation by placing 2 DGs and 3 DGs in both the test systems. The Figures 4 (a) and 5 (a), are the convergence characteristics of 2 DGs placement for 33 and 69 test systems, respectively. Both these curve are obtained by moving towards inward and finds the optimal point for the 2 DGs placement. Whereas, in the case of 3 DG units placement the Figures 4 (b) and 5 (b) are the corresponding curves for 33 and 69 test systems, respectively. In these curves the first objective function get reduced but second objective function is increased. There is an increase in voltage deviation but, with acceptable level i.e. the deviation of values are in third digit fraction.
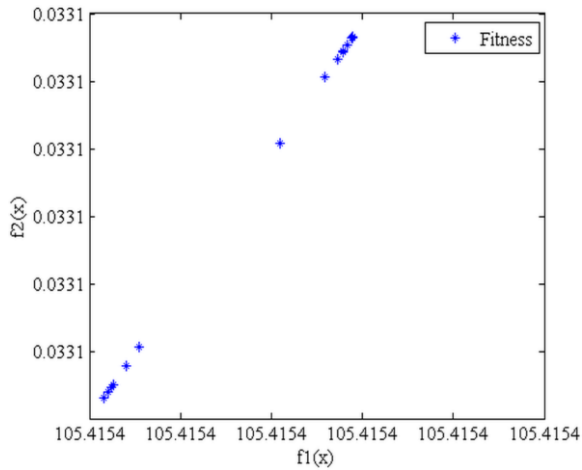
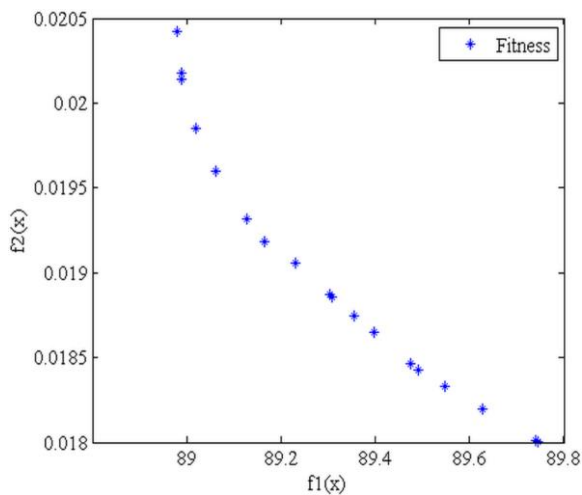Figure 5. a). For the placement of 2 DGs

Figure 5. b). For the placement of 3 DGs
Figure 5. Fitness curve for 69 bus system

Figure 6. Improved voltage profile of 33 bus system
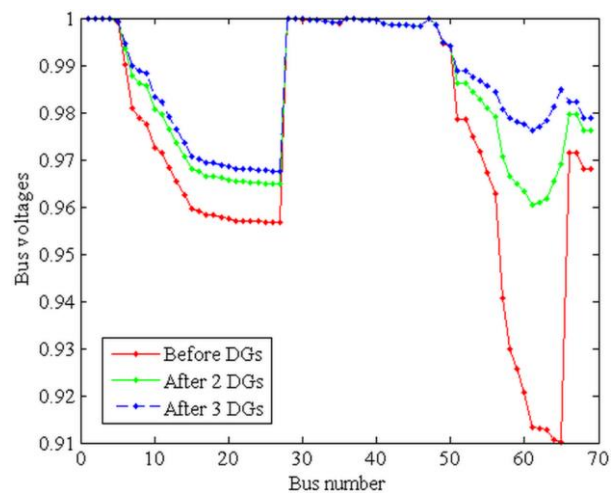
Figure 7. Improved voltage profile of 69 bus system

It is obvious from Table 5; there is a percentage reduction in real power losses, while employing two DGs in top two optimal locations for both the test systems. The value of percentage reduction in real power losses are 41.93% and 52.99% for 33 bus and 69 bus systems, respectively. It is also interesting to observe that the further percentage reduction in real power losses, if the DG units are placed in all three identified locations. From Table 5, the values of percentage reduction in real power losses are 44.61% and 60.36% for 33 bus and 69 bus systems, correspondingly.

The voltage comparison graphs between base case with the placement of 2 DG units and 3 DG units for 33 bus and 69 bus systems are illustrated on Figure 6 and Figure 7, correspondingly. It is very obvious from these voltage comparison graphs that the voltages of all buses get increased, if 3 DG units are installed in all three identified locations than to place 2 DG units only in two top optimal locations.
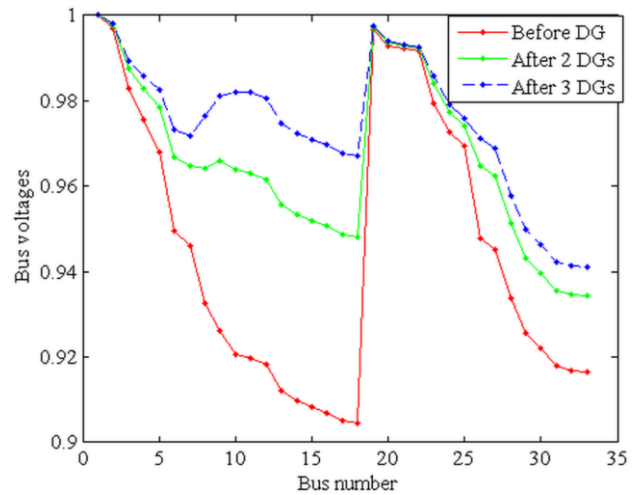
The results arrived in this proposed algorithm with NSGA II is compared with the results reported in existing literature [17] and [22], using Power Stability Index (PSI) and Golden Section Search (GSS) algorithm, respectively. The comparison of results for DG sizes and losses for 69 bus system is also tabulated in Table 6.

Table. 6
Comparison of results

Method	DG location	DG sizes in KW	Real power losses (KW)
Proposed algorithm with NSGA II	64, 65, 63	1773.0	85.485
Using GA [21]	64,65,63	1668.0	89.073
Using PSI method [17]	61	1863.1	NR
Using GSS method [22]	61	1872.7	NR

While selecting the generators for any application, it is strongly recommended to select more numbers of units with medium sizes than to select large size of single unit. This rule is strictly followed by the design engineers in

order to ensure the operating reliability of the generating system. In existing literature, single unit of large size DG is installed at a single location, but in this proposed approach three medium size DG units are installed at three different locations. From Table 6, the proposed approach is evidently reduces the real power losses, which is not reported in other two literature, reduces the fuel cost by the reduction of total DG capacity and ensures the reliability of test system by having more numbers of DG units.

6. Conclusion

The exploration of most favourable location and sizing of multiple DG units in radial distribution system is established in this work. The improper location and incorrect size of DG units create some hectic problems like fault current increase, power quality disturbances, voltage instability and upset of relay coordination in existing protection schemes. Therefore, this research effort investigates the relevant locations of multiple DG units on the basis of Final Node Voltage Discrepancy Factor, which is a good indicator in pointing out the opt locations for multiple DGs.

The problem framed in this attempt is formulated as an optimization problem using an efficient multi objective evolutionary algorithm NSGA II with two objectives as minimizing real power losses and bus voltage deviations subject to diverse numbers of equality and inequality constraints. It is evidently confirmed that the interconnection benefits of DG get enhanced with the increased penetration of DG units. A significant improvement in voltage profile is also observed and demonstrated in this investigation as a supplementary gain by the optimal DG units' placement. The results derived from this methodology are compared with contemporary literature and this effort has proved to be superior, fast and simple to all other methods.

In the current situation, power system excepting a renewable energy source as distributed generations is impossible. Under this scenario, this proposed approach undoubtedly paves some innovative and progressive corridors both for energy producers and market operators to handle the complex problems available with it.

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