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Distributed Generation Allocation Considering Uncertainties

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Abstract

This paper presents a distribution generation (DG) allocation strategy for radial distribution networks under uncertainties of load and generation using genetic algorithm (GA). Backward / forward (BW/FW) sweep algorithm is used for load flow. The uncertainties of load and generation are modeled using fuzzy-based approach. The optimal locations of DG and size to minimize system loss under specified constraint is obtained by GA. The test is done for different scenarios of power supplied by DG i.e., active and reactive power and it's combination. Further, all scenarios are run for different cases of load and generation i.e., different combinations of deterministic and fuzzy data for load and generation. The locations and sizes of DG obtained by fuzzy-based approach are found to be different from those obtained with the deterministic approach. The results obtained by the fuzzy-based approach are found to be comparatively efficient for the future increasing load. The proposed approach is demonstrated on the IEEE 33-node test network.

Keywords

Distributed generation (DG), fuzzy load and generation, Defuzzification, genetic algorithm (GA)

1. Introduction

Distributed Generation (DG) is a small-scale generation source with an output ranging from 1 kW to several megawatts and usually installed at the distribution level. Due to recent advances in the small-scale generation technology, DG is now widely employed in both the utility distribution grid and on the other side of the network.

As the electrical energy demand is growing yearly, a large amount of capital cost is needed to install new power stations, expansion of transmission, and distribution lines. These amounts can be reduced by using distributed generators which can be conveniently located closer to load centers. The siting and sizing of the renewable distributed generation (RDG) are the most challenging part for most utilities to be determined. A proper siting and sizing of DG has both economic and technical benefits[1].

The major technical benefits include [2]
- Reduction of line losses
- Voltage profile improvement
- Increased overall energy efficiency
- Enhanced system reliability and security
- Relieved T and D congestion.

The major economical benefits include:
- Deferred investments for upgrades of facilities
- Reduced O and M costs of some DG technologies
- Reduced fuel costs due to increased overall efficiency
- Lower operating costs due to peak shaving and
- Increased security for critical loads.

Distributed generation is a generating plant serving a customer on-site or providing support to a distribution network. It is predicted that DG would have a share of about 20% of new generating units being on lined. DG applications are growing due to environmental and economic issues, technological improvements, and privatization of power systems. DG application, however, has positive and negative side effects for public industries and consumers.

However, these advantages cannot be fully exploited if inappropriate siting, and sizing of DGs is determined. The location of distributed generation (DG) may be either a positive or negative impact on the power system network.

Generally, DG effects in distribution networks depend on several factors such as the DG place, technology issues, capacity, and the way it operates in the network. DG can significantly increase reliability, reduce losses, and save energy while it is cost-effective, though it suffers from some disadvantages because of the isolated power quality functioning, and voltage control problems.

In some approaches, the objective function(s) formulation is done in view of the optimization of DG installation and operational cost, cost of energy purchase, and cost of energy losses in the presence of DG. The goal is to determine the optimal location(s) and size(s) of DG units in a distribution network. In the present paper, the optimization is carried out under the constraints of maximum DG sizes, thermal limit of network branches, voltage limit of the nodes, and generation limit. The objective functions are minimization of network power loss, node voltage deviation, and lodability limit of the line. GA based approaches are used as a solution strategy.

2. Problem statement

In most of the planning models, DG allocation in a distribution network is done using deterministic load demand and DG generation. Generally, the peak load demand of each node and the maximum capacities of each DG unit are used to determine the benefit of DG allocation. These are generally obtained from historical data and different forecasting techniques, e.g., load growth forecast and weather forecast. However, these forecasting techniques are always subject to some errors because of the uncertainty and inherent variability in load demand, solar irradiation, and wind speed. In this paper, load demand uncertainty (LDU) and DG power generation uncertainty (PGU) are incorporated into network planning.

3. Methodology

3.1 Fuzzy Load and Generation Model

A fuzzy number is a special case of a convex, normalized fuzzy set representing an extension of real numbers. It is used to transform the verbal declaration of an uncertain event or an interval into its mathematical form. In this work, the LDU and PGU are represented by triangular fuzzy numbers, as shown in Figure 1. In practice, the most probable load in a node of a distribution network is forecasted by utility companies with high and low bounds [3].

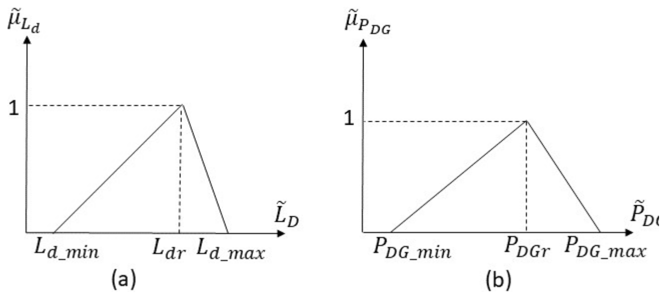

Figure 1: Fuzzy membership function for: (a)load demand and (b) DG generation

In which L_{d-min}, L_{dr} and L_{d-max} represent the minimum possible load demand, load demand with highest possibility of existence, and maximum possible load demand for a node, respectively and so on for the DG power generation.

3.2 Fuzzy Distribution Load Flow with DG Model

The fuzzy distribution load flow technique [3], [4]is used for planning with fuzzy load and generation models. The fuzzy load flow is carried out by taking β -cuts of the fuzzy load corresponding to two values for β i.e., β=0 and β=1. The first one is for the whole range of fuzzy load and DG generation and the second one is for the load demand and DG generation with highest possibility of existence [3]. The fuzzy distribution load flow yields fuzzy numbers for the node voltages and branch power flows for a distribution network.

Fuzzy possibility distribution functions [4] as shown in Figure 2 are basically left (L) and right (R) types of flat fuzzy numbers M = $(\beta_i^l, \beta_i^r, \alpha_i^l, \alpha_l^r)$ such that $\exists$ (β_i^l, β_i^r) and μ_m(x) = 1 $\forall$ x ε $[\beta_i^l, \beta_i^r]$ and

$$\mu_m(x) = \begin{cases} L(x) & \text{if } \alpha_i^l \leq \text{x } \beta_i^l, \\ R(x) & \text{if } \beta_i^r \leq \text{x } \leq \alpha_i^r, \\ 0 & \text{othewise,} \end{cases} \tag{1}$$

where

$$L(x) = \frac{x - \alpha_i^l}{\beta_i^l - \alpha_i^l} and \tag{2}$$

$$R(x) = \frac{x - \alpha_i^r}{\beta_i^r - \alpha_i^r} \tag{3}$$

Here x represents the individual KVA demand of distribution transformer. So above equation becomes as

$$\mu_m(KVA_i) = \begin{cases} L(KVA_i) & \text{if } \alpha_i^l \le KVA_i \le \beta_i^l, \\ R(KVA_i) & \text{if } \beta_i^r 0 \le KVA_i \le \alpha_i^r, \\ 0 & \text{otherwise.} \end{cases} \quad (4)$$

$$L(KVA_i) = \frac{KVA_i - \alpha_i^l}{\beta_i^l - \alpha_i^l} \quad (5)$$

$$R(x) = \frac{KVA_i - \alpha_i^r}{\beta_i^r - \alpha_i^r} \quad (6)$$

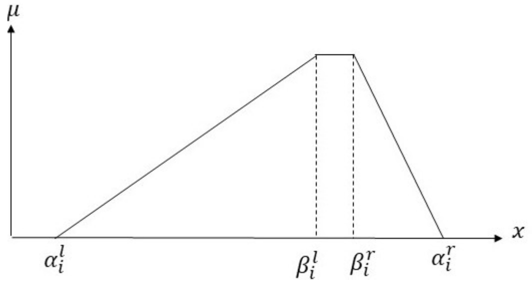

Figure 2: Fuzzy number representing a qualitative linguistic load prediction.

For each value of $\mu_m(KVA_i)$,two different values of KVA_i load are obtained from equation. Therefore, for each membership value, two load flow runs are required.

3.3 Defuzzification methods

These are the methods of fuzzy to crisp conversion. Different defuzzification methods are as follows [5].
1. Fuzzy removal techniques(α-cut method).
2. Maxima methods(First of maxima(FOM), Last of maxima(LOM), Mean of maxima(MOM)).
3. Centroid method(Center of sum(COS) and Center of gravity(COG)).
4. Total distance criterian(TDC) index.

The COG provides relatively higher weights to lower membership values, whereas the MOM neglects lower membership values. The TDC or removal value is the average of the sum of areas under the left and right sides of the fuzzy membership function corresponding to a α-level. The removal method used in this study yields a reasonably good representation of a fuzzy set [5].

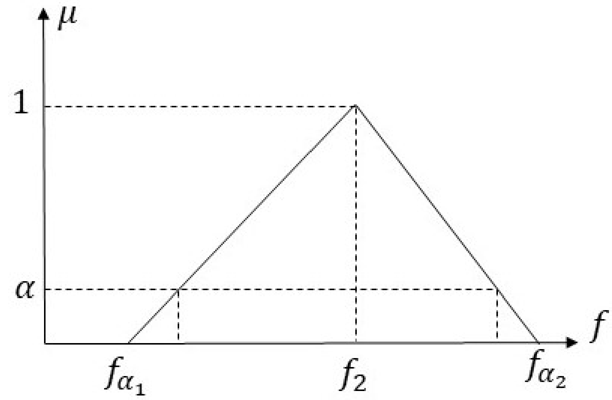

Figure 3: Fuzzy removal technique for a possibilistic objective function.

For a triangular fuzzy number, the removal Rem($\tilde{f}$) of a fuzzy objective function ($\tilde{f}$) corresponding to a α-cut is defined as [5]

$$Rem(\tilde{f}) = (f_{\alpha 1} + 2f_2 + f_{\alpha 2})/4 \quad (7)$$

where [$f_{\alpha 1}$], [$f_{\alpha 2}$] is defuzzified form for the function $\tilde{f}$ derived using the α-cut concept of defuzzification and f_2 is the point corresponding to unity membership value. Two fuzzy numbers $\tilde{a}$ and $\tilde{b}$ can be compared using their removal values, i.e., Rem($\tilde{a}$) and Rem($\tilde{b}$), respectively. The value of α is user specific.

3.4 Objectives

In this work, the objective function is the minimization of the weighted sum of the ratio of network power loss with DG to that of without DG ($\tilde{f}_p$) and the ratio of maximum node voltage deviation with DG to that of without DG ($\tilde{f}_v$) as given below [2].

$$f = k_p Rem(\tilde{f}_p) + k_v Rem(\tilde{f}_v) \quad (8)$$

Where,

$$\tilde{f}_p = \frac{\sum_i^{N_{Br}} \tilde{P}_{L_i}^{\ with\_DG}}{\sum_i^{N_{Br}} \tilde{P}_{L_i}^{\ base}} \quad (9)$$

and

$$\tilde{f}_v = \frac{max(V_{sub} - \tilde{V}_i^{with\_DG})_{i=1,.....,N_B}}{max(V_s ub - \tilde{V}_i^{base})_{i=1,.....,N_B}} \quad (10)$$

This objective function is optimized under the following technical constraints.
1) Node voltage constraint

$$V_{min} \le Rem(\tilde{V}_i^{with\_DG}) \le V_{max}. \quad (11)$$

2) Thermal limit constraint of each branch

$$Rem(\tilde{I}_i) \leq I_{Cap_i}. \tag{12}$$

3) DG power capacity constraint

$$P_{DG\_min} \leq Rem(\tilde{P}_{DG_i}) \leq P_{DG\_max}. \tag{13}$$

3.5 Flowchart

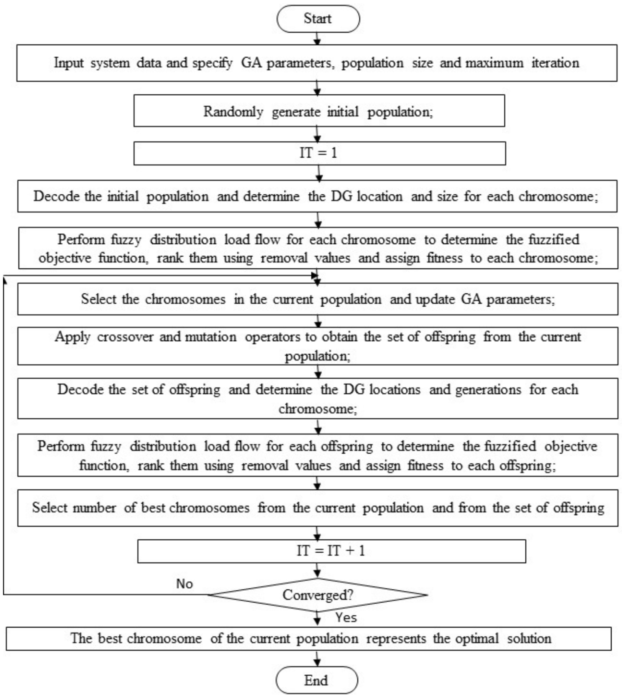

Figure 4: Flowchart for the overall planning algorithm using GA.

4. Results and discussion

The test is performed to demonstrate the proposed algorithm using a 33-node distribution network. The system contains a single substation located at node 1. The line data and load data of the 12.66 kV IEEE 33-node system are taken from [6] in which total connected load is 3.715 MW and 2.3 MVAR. The maximum and minimum allowable node voltage limits are set as 1.05 and 0.95 p.u., respectively. The maximum number of DG integration is considered to be 3. The maximum DG size for a solution is determined according to a given DG penetration level. Performance comparison of the solutions obtained with fuzzy-based and deterministic planning is done by considering the following four scenarios.

Scenario1: DG supplying only active power.
Scenario2: DG supplying only reactive power.
Scenario3: DG supplying active power but consuming reactive power and
Scenario4: DG supplying both active and reactive power.

All the above-mentioned scenarios are repeated under following four cases.
Case A: Deterministic load and generation.
Case B: Fuzzy load and deterministic generation.
Case C: Deterministic load and fuzzy generation.
Case D: Fuzzy load and generation.

In deterministic cases, peak load and maximum generation are used. The uncertainty of load and generation is modeled by using a triangular fuzzy number. The scenario of load and generation are considered as follows.
Load demand, $\tilde{L}$ = (0.4, 1, 1.4) p.u. of peak load demand. DG generation = (0.2, 1, 1.6). Same weighing factors (i.e., $k_p = k_v = 0.5$) for both the objective functions are taken.

The proposed scheme is run for the multiple DG penetration to optimize the same objective value. The results obtained are as follows.

4.1 Result comparison under each scenario

(1) DG supplying only active power (Scenario 1)

Table 1: Result for DG supplying only active power

Network Parameters	without DG	Case A	Case B	Case C	Case D
Power loss (kW)	210.998	82.091	75.630	76.217	74.864
DG location	-	7,15,31	14,24,31	13,24,29	14,25,30
DG size (MVA)	-	1.042	0.839	0.714	0.802
	-	0.761	0.908	0.769	0.601
	-	0.914	0.893	1.174	1.105
Total DG size (MVA)	-	2.717	2.640	2.657	2.508
DG penetration %	-	59.73	58.04	58.41	55.13
Power factor	-	1	1	1	1

(2) DG supplying only reactive power (Scenario 2)

Table 2: Result for DG supplying only reactive power

Network Parameters	without DG	Case A	Case B	Case C	Case D
Power loss (kW)	210.998	242.564	174.410	176.771	174.003
DG location	-	12,18,28	13,24,32	6,15,24	14,24,26
DG size (MVA)	-	1.064	0.621	0.833	0.454
	-	0.221	0.607	0.388	0.631
	-	1.375	0.461	0.337	0.730
Total DG size (MVA)	-	2.660	1.689	1.588	1.515
DG penetration %	-	58.48	37.13	34.91	33.30
Power factor (lead)	-	0	0	0	0

(3) DG supplying active power but consuming reactive power (Scenario 3)

Table 3: Result for DG supplying active power but consuming reactive power

Network Parameters	without DG	Case A	Case B	Case C	Case D
Power loss (kW)	210.998	229.896	173.877	177.244	174.467
DG location	-	6,15,28	13,24,31	6,14,24	14,24,27
DG size (MVA)	-	0.264	0.668	0.748	0.479
	-	0.998	0.644	0.379	0.492
	-	1.208	0.434	0.444	0.708
Total DG size (MVA)	-	2.470	1.746	1.571	1.678
DG penetration %	-	54.30	38.38	34.53	36.89
Power factor (lag)	-	0.85	0.85	0.85	0.85

(4) DG supplying both active and reactive power (Scenario 4)

Table 4: Result for DG supplying both active and reactive power

Network Parameters	without DG	Case A	Case B	Case C	Case D
Power loss (kW)	210.998	31.373	25.342	26.006	18.942
DG location	-	11,25,32	8,14,30	13,24,29	14,25,30
DG size (MVA)	-	1.424	0.706	0.900	0.753
	-	0.323	0.745	0.438	0.688
	-	0.938	1.239	1.267	1.283
Total DG size (MVA)	-	2.685	2.690	2.605	2.724
DG penetration %	-	59.03	59.14	57.27	59.88
Power factor (lead)	-	0.85	0.85	0.85	0.85

The voltage profile comparison of each cases for scenario 4 is shown in figure below (figure 5-8). Case A is compared with the case of without DG and other cases (cases B-D) are compared with the case A.

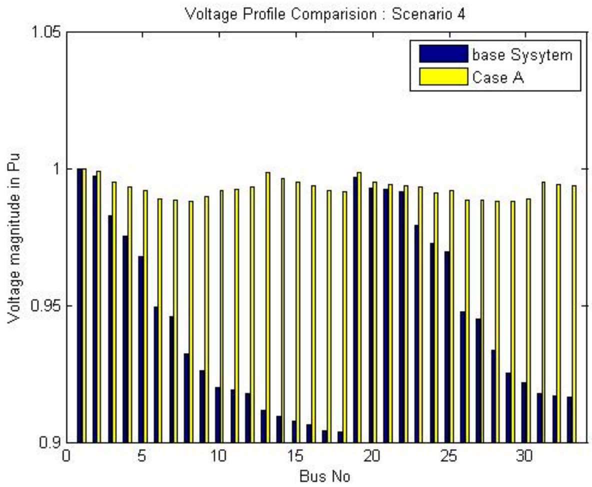

Figure 5: Voltage profile comparison of without DG and case A.

When multiple DG is penetrated, then voltage profile is improved than that of without DG.

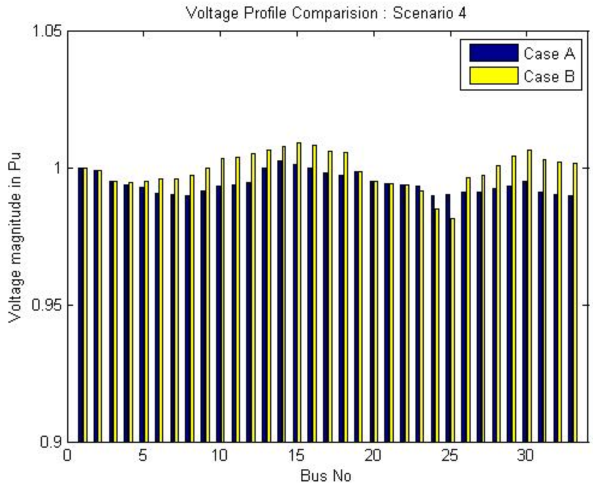

Figure 6: Voltage profile comparison of case B with case A.

The voltage profile is slightly changed with comparison to deterministic case but no one is under limit violation.

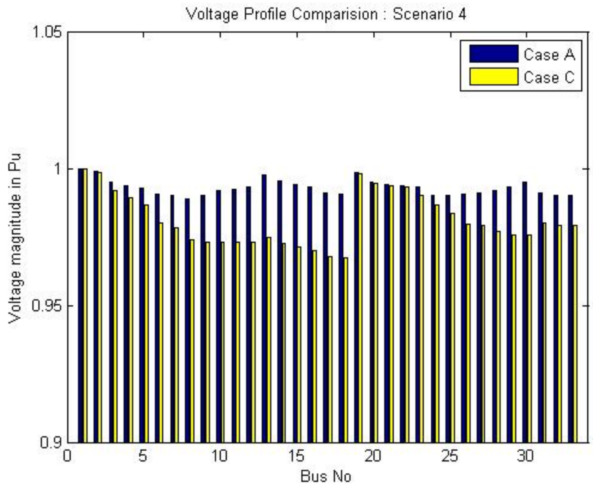

Figure 7: Voltage profile comparison of case C with case A.

The voltage profile is slightly changed with comparison to deterministic case.

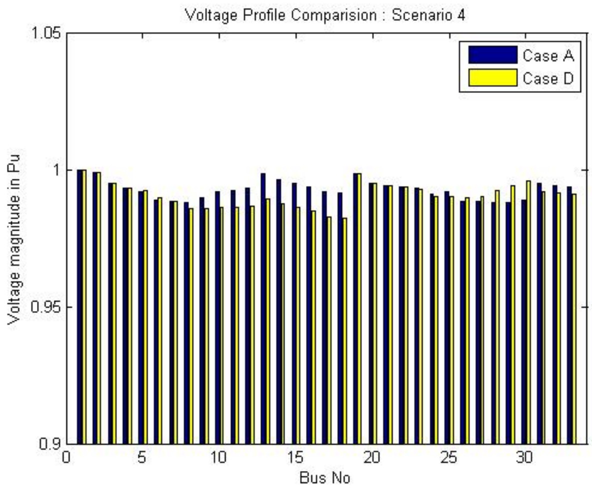

Figure 8: Voltage profile comparision of case D with case A.

The voltage profile is slightly changed with comparison to deterministic case.
Similar voltage profile graphs are obtained for other scenarios also(not shown here).

If we see case wise under the same scenario then we can find that, the power loss and minimum node voltage of the solutions obtained with different planning cases (cases A-D) are not much different for an equal amount of DG penetration. However, these solutions are different, in view of locations and sizes of DG units as shown.So, for minimization of losses proper siting and sizing are required.

So, the modeling of load and generation using a fuzzy-based approach is beneficial because the solution obtained with this approach can efficiently work on higher future load condition as compared to the deterministic planning. For this purpose, proper sizing and siting of DG are required as observed from the above analysis.

The results also show that significant amount of power loss reduction and improvement in node voltage magnitude is obtained with the placement of DG supplying reactive power. It is expected because both active and reactive power compensations take place for this type of DG integration.

4.2 Scenario wise result comparison

When we observe scenario wise then we find that power loss is minimum for case 4 in all scenarios.

Table 5: Table for result of summary

Network Parameters	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Power loss (kW)	74.864	174.003	174.467	18.942
DG location	14,25,30	14,24,26	14,24,27	14,25,30
DG size (MVA)	0.802	0.454	0.479	0.753
	0.601	0.631	0.492	0.688
	1.105	0.730	0.708	1.283
Total DG size (MVA)	2.508	1.515	1.678	2.724
DG penetration %	55.13	33.30	36.89	59.88
Power factor	1	0	0.85(lag)	0.85(lead)
Best case	Case D	Case D	Case D	Case D

It is found that, for DG consuming reactive power (Scenario 3), the system loss is high. It is expected because this type of DG cannot compensate reactive power. The reactive power to be fed to the DG is to be supplied from other sources. For the DG supplying both active and reactive power (Scenario 4), the loss is minimum. It is expected because both active and reactive power compensations take place for this type of DG integration. So, we can conclude that case 4 under scenario 4 is the best case.

4.3 Performance comparison with an existing approach

The table shows the result of the location and size of DG for optimization of objective value in terms of power loss for deterministic load and generation, with the proposed approach and the result obtained is compared with the existing approach.Here, it is considered that, the DG supplying both active and reactive power.

Table 6: Result of power loss and DG location using single DG

Network parameters	without DG	Approach by GA without fuzzy[2]	Solution A	Solution B
Power loss (kW)	210.998	78.413	72.872	68.170
DG location	-	30	29	6
DG Size (MVA)	-	1.950	2.094	3.105
Power factor(lead)	-	0.95	0.85	0.85
Loss saving (kW)	-	132.557	138.126	142.828
Loss saving in kW per DG inj. in MVA	-	67.977	65.962	45.999
DG penetration %	-		46.04	68.27

Here, solution A is for 50% and Solution B is for 100% penetration case. The result of the proposed approach is nearly equal to the result without a fuzzy case by GA. The DG size as obtained in solution A is nearly equal to the solution provided in [2]. In both solutions, the power loss saving per DG injection is not much different.

4.4 Effect of load growth

The effect of load growth is checked for all scenarios. The effect of load growth for scenario 4 is shown below.

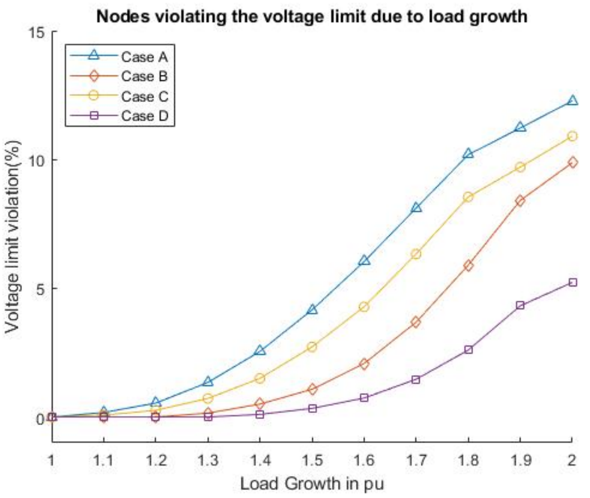

Figure 9: nodes violating the voltage limit due to load growth.

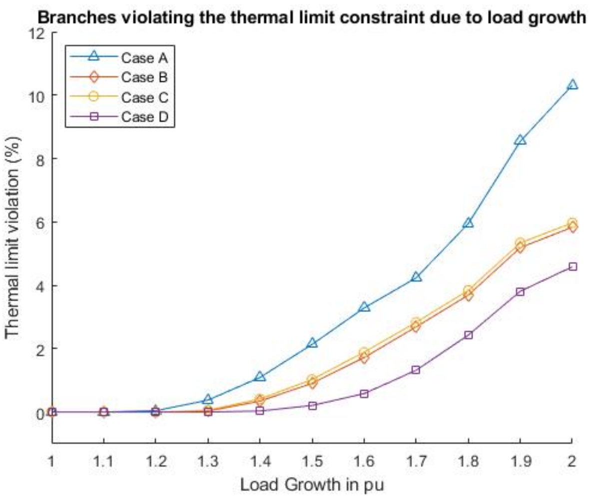

Figure 10: Branches violating the thermal limit constraint due to load growth.

The performances of the solutions obtained with different planning cases are assessed with load growth test to test their capabilities in sustaining future load. All the nodes are subjected to equal per unit load growth rate. The performances of the solutions obtained with each planning case (i.e., Cases A–D) are measured on the basis of percentage of branches violating the thermal limit constraint and the percentage of nodes violating the voltage limit. The results obtained with the IEEE 33-node systems are shown in Figures 9 and 10, respectively. It is observed that the percentage of the branches violating the thermal limit and the percentage of nodes violating the voltage limit are comparatively less in case of the solutions obtained with fuzzy load and generation as compared to the solutions obtained with deterministic load and generation. The solutions obtained with Cases B–D can work with 20%–40% load growth without any constraint violation. Case D solution exhibits the least constraint violation for the 33-node system. This illustrates that the solutions obtained with fuzzy-based planning can efficiently work on higher loading condition that may arise due to future load growth than the solutions obtained with the deterministic planning.

Similar graphs are obtained for other scenarios also.

5. Conclusion

In this paper, the DG allocation in the distribution network to minimize system loss is done under the uncertainty of load demand and generation of DG. The uncertainty modeling is done using a fuzzy-based approach and optimization of location and size is obtained by GA. The salient observations from the results obtained are as follows.

1. DG integration is beneficial only if it is penetrated at some specific nodes to obtain significant improvement in power loss and node voltage.
2. Although the optimal power loss and minimum node voltage are found to be nearly equal in deterministic and fuzzy-based approaches, the optimal locations and sizes for DG are much different.
3. The modeling of load and generation using a fuzzy-based approach is beneficial because the solution obtained with this approach can efficiently work on higher future load condition as compared to the deterministic planning.

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