ISSN 2229-5518

A Comprehensive Distributed Generation Planning Optimization with Load Models

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Abstract— In this paper a comprehensive model for Distribution Systems Planning (DSP) in the case of using Distributed Generation (DG), with regard to load models is provided. Proposed model optimizes size and location of the distributed generation. This model can optimize investment cost in distributed generation better than other solutions. It minimizes the operating costs and total cost of the system losses. This Model affects the optimum location and size of the distributed generation in distribution systems significantly. Simulation studies based on a new multiobjective evolutionary algorithm is achieved. It is important that in the analysis made in this paper, DG is introduced as a key element in solving the DSP. Moreover, the proposed method easily and with little development can satisfy the other goals.

Index Terms— Economic Analysis, Distributed Generation, Distribution Systems Planning, Load Models.

1 Introduction

Distribution Companies (DISCOs) should apply new strategies in order to increase economic power generation (because of load growth) and giving services to customers and not being remained behind in market competition of electrical power. By using of new alternatives, these goals are available for solution of planning problem of distribution system in addition to traditional ones.

The load growth value is predicted in traditional options so that it may reach to a certain level. Then, a new capacity shall be added to the given system. By considering new electrical substations or via expanding the capacity of the existing substations through new feeder, such a new capacity will be obtained by both of them [1], [2]. One of the new options to planning for increase in capacity is Distributed Generation. DG may lower total costs in the system, decrease load flow within system, and improve voltage profile [3], [4], and leading to decreased system losses [3]-[5], relieving the heavy loaded feeders and increase lifetime of equipments [6].

From [7]-[10], a perfect revision is carried out on load models which are applicable to load flow and dynamic studies. Such studies are conducted on frequency or voltage dependent load models.

During recent years, the studies on evolutionary algorithms have shown that these methods have not many of previous problems [11]. In general, these methods may obtain multiple pareto optimal solutions in one single run.

This paper suggests using of DG by DISCOs, as a new economic tool for Distribution System Planning (DSP) Problem. The proposed approach makes decision on DG optimal location and size and the optimized power which should inject through distribution system. The derived results from this model may be used for bill estimation of customers of Distribution Company. Two comprehensive scenarios will be discussed to cover various probabilities. Similarly, in this paper, the effect of load models on DG location and size planning optimization has been argued. We will see that load models considerably affect on planning for location and size of DG within distribution networks. Also, an approach is given to solve the problem which is based on Strength Pareto Evolutionary Algorithm (SPEA).

2 Distribution system planning model

In the case of load growth in power electricity market, DISCO has two options to meet such demand.

1- Scenario A: Purchasing the required extra power from main grid and extending the existing substations in distribution network. At this scenario, DISCO has to develop the existing substations by installation of new transformers and upgrading some existing feeders' capacities if they have not sufficient thermal capacity, and purchasing power from the main grid.

2- Scenario B: Investment on DG as an alternative candidate option for solving the DSP problem and purchase power from main grid and extending of the existing substation.

A. Model Formulation

This paper aims to minimize the investment and operating costs of DG, reduction of active and reactive losses, improvement in voltage profile and relieving the heavy loaded feeders. It also conducts study about impact of voltage dependent load models, namely, residential, industrial and commercial load models within different scenarios of planning. Load models are defined as follows.

$$P_i = P_{0i}\left|V_i\right|^{\alpha} \; / \; Q_i = Q_{0i}\left|V_i\right|^{\beta} \qquad (1)$$

where P_i and Q_i are active and reactive power at bus i, P_{0i} and Q_{0i} are active and reactive power operating point in bus I, V_i is voltage in bus i and α and β are active and reactive power exponents. In a constant power model conventionally used in power flow studied α = β = 0 is assumed. The values which are used for are active and reactive power exponents in industrial, residential and commercial load models in this paper are given in Table 1 [12].

TABLE 1
EXPONENT VALUES

Load Type	α	β
Constant	0	0
Industrial	0.18	6.00
Residential	0.92	4.04
Commercial	1.51	3.40

During studying residential model, it is assumed that the system only has residential loads. Similarly, this is also applied for industrial and commercial loads where all these loads are of industrial and commercial types, respectively. In real situations, loads aren't exactly residential, commercial and industrial, so the mixture load class should be foreseen for distribution system. There are several ideas to study on effect of DG within distribution systems. One of such ideas is the computation of multiple indices to describe the effects of disperse generations on distribution system. These indices are

1) Active and Reactive Power Loss Indices (ILP and ILQ):

$$ILP = \frac{\lfloor P_{LDG} \rfloor}{\lfloor P_L \rfloor} \times 100 \,/\, ILQ = \frac{\lfloor Q_{LDG} \rfloor}{\lfloor Q_L \rfloor} \times 100 \qquad (2)$$

Where P_{LDG} and Q_{LDG} are total loss of active and reactive power distribution system with DG, P_L and Q_L are total loss of active and reactive power of total system without DG in the distribution network.

2) Voltage Profile Index (IVD): One of the advantage of proper location and size of the DG is the improvement in voltage profile.

$$IVD = \max_{i=2}^{n}\left(\frac{|V_1| - |V_i|}{|V_1|}\right) \times 100 \qquad (3)$$

3) MVA Capacity Index (IC): This informational index gives information in the field of system necessities for promoting transmission line.

$$IC = \max_{i=2}^{n}\left(\frac{|S_{ij}|}{|CS_{ij}|}\right) \qquad (4)$$

4) Cost Index M$ (J):

$$\begin{aligned} J = {} & \sum_{i=1}^{M} C_{fi}\left(S_{DGi}^{Max} + BK\right) + 8760\sum_{t=1}^{T}\sum_{i=1}^{M}\beta^{t} C_{ri} S_{DGi} \\ & + 8760\sum_{t=1}^{T}\beta^{t}\sum_{i=1}^{TN}\sum_{j=1}^{M}\frac{\Delta V_{ij}^{2}}{|Z_{ij}|}\, pf.C_e + A + B \end{aligned} \qquad (5)$$

$$A = \sum_{i=1}^{SS}\sum_{u=1}^{TU} C_{i,u} + \sum_{i=1}^{TN}\sum_{j=1}^{M} C_{ij} + 8760\sum_{t=1}^{T}\beta^{t}\sum_{i=1}^{TU} pf.C_e.S_{i,u} \qquad (6)$$

$$B = \sum_{i=1}^{TN}\sum_{j=1}^{M} C_{ij} + 8760\sum_{t=1}^{T}\beta^{t}\sum_{i=1}^{TU} pf.C_{int}\left(S_{int}\right).S_{int}\left(S_{int}\right) \qquad (7)$$

$$\beta^{t} = \frac{1}{(1+d)^{t}} \qquad (8)$$

where BK denotes backup capacity of DG (MVA), β is present worth factor, C_f as investment cost in distributed generations ($/MVA), C_r DG operating cost ($/MVA), C_e is Electricity market price ($/MWh), C_{ij} is Total feeder cost from i to j ($), $C_{i,u}$ as Potential transformer u in existing substation i cost ($), C_{int} Intertie electricity market price ($/MWh), D is total load demand (MVA), d discount rate, i and j are bus indices, J as cost index ($), M is total number of load buses, pf as system power factor, S_{DG} is generation power of distributed generations (MVA), S_{DG}^{Max} denotes maximum capacity of distributed generations (MVA), S_{ij} power flow in feeder connecting bus i to j (MVA), S_{ij}^{Max} is feeder thermal capacity between i and j buses (MVA), $S_{i,u}$ is dispatched power of transformer u in substation i (MVA), S_{int} as amount of power imported by the intertie (MVA), S_{SS} is power purchased by the distribution utility (MVA), S_{SS}^{Max} is capacity of existing substation (MVA), SS as number of existing substations, t incremental time intervals (year), T horizon planning year (year), TN total number of system buses, TU total number of substation transformers, V bus voltage (V), V_n system nominal voltage (V), ΔV maximum permissible voltage drop (V), and Z_{ij} feeder impedance between buses i and j (ΩohmsΩ) [13].

Optimization should be minimized by consideration of various operational constraints. Such constraints are given in (9) – (14).

1) Total Power Conservation: By considering losses of lines and power which is generated by DG (if it exists), sum of input and output powers should be equal to existing total load demand.

$$\sum_{i=1}^{TN}\left\{S_{ij} - \frac{\Delta V_{ij}^{2}}{|Z_{ij}|}\right\} - \sum_{i=1}^{M} S_{ji} + S_{DGj} = D_j, \forall j \in M \qquad (9)$$

2) Distribution Feeder's Thermal Capacity: Distribution system's feeders have a capacity limit for the total power flow through it.

$$S_{ij} \le S_{ij}^{Max}, \forall i \in TN, \forall j \in M \quad (10)$$

3) Distribution Substation's Capacity: Power which is generated by substations shall be at the substations capacity level.

$$\sum_{j=1}^{M} S_{SSij} \le S_{SSi}^{Max}, \forall i \in SS, \forall j \in M \quad (11)$$

4) Voltage Drop: The DISCO provides the predetermined maximum permissible voltage drop limit.

$$0 \le \left| V_i - V_j \right| \le \Delta V, i \in TN, j \in M \quad (12)$$

5) DG Operation: The generated power by DG shall be lesser than DG capacity.

$$S_{DGi} \le S_{DGi}^{Max}, \forall i \in M \quad (13)$$

6) Intertie's Delivery Power Capacity Limit: DISCO determines the intertie's delivery power cost rates. Rate of delivered power depends on the purchased power value by distribution network.

$$\begin{aligned} C_{int}(S_{int}) &= 1.00 C_e, \forall S_{int} \in \{0,5MVA\} \\ &= 1.05 C_e, \forall S_{int} \in \{5,10MVA\} \\ &= 1.15 C_e, \forall S_{int} \in \{10,15MVA\} \\ &= 1.35 C_e, \forall S_{int} \in \{15,20MVA\} \end{aligned} \quad (14)$$

B. Primary Distribution System under Study

The existing primary distribution system under this study is a 9-bus system [13]. This system has a 40MVA substation. Load growth which has been predicted for 4 years is approximately 28% (51.1 MVA). The given system has 4 feeders with thermal capacity of 12 MVA.

Based on market indexes in 2002 (in USD), 70 \$/MWh and 0.5 M\$/MVA have been considered as prices of electricity market and natural gas generator set, respectively. DGs have a capacity which is multiples of 1 MVA at a generated electricity price of 50 \$/MWh. An extra DG with 1 MVA capacity has been allocated for each DG as backup [13]. It is assumed that DG has unity power factor [12]. The maximum capacity of DG has been provided for each bus (maximally 4 units plus one unit as backup). This is done in order to keep distributed generation concept and DG not to be concentrated as a centralized plant so the existing main substation to be used at maximum level.

Two three phase transformers with 10 MVA power capacity and 0.2 M\$ price for each one may be also installed to expand the main substation. The cost of upgrading the existing primary distribution feeder with another of higher capacity is 0.15 M\$/Km. The price of other existing equipments and feeders will be considered zero. System power factor and discount rate are also 0.9 and 12.5%, respectively. During all optimization runs, population size and generations maximum number are 300 and 750 respectively. The maximum size of Pareto's optimal set includes 20 solutions. The probabilities of crossover and mutation are 0.9 and 0.01, respectively. Recently, the studies on evolutionary algorithms have indicated that these algorithms may be effective in removal of problems of older methods. The applied optimization algorithm is SPEA [14].

3 Analysis and Results

Two argued main scenarios in this paper are simulated in order to evaluate preference of investing on DGs in solving DSP problems in comparison with other traditional planning options.

3.1 Scenario A

In this scenario, DG size is zero. This model gives the optimal cost of substation's new transformers, and the power which is dispatched by these transformers, and the amount of delivered power from main grid to distribution network for all types of load models (NL is number of lines upgrading).

Results which obtained from optimization model are given in Table 2 for all load models. It is seen that load models affect on solutions. It is possible that the obtained solution does not apply to industrial load by using of constant load model. Such an impact from load models is also observed for residential, commercial, and composed models. More money should be spent by purchase of new equipments and due to compensation for losses so these costs are added to customers' bills.

3.2 Scenario B

Table 3 indicates the solutions that are derived for investment on DG option. Comparing these results with the results of above scenario, we can see that investment on DG presents a better planning. For constant load model, four groups of DG with capacities of 4, 4, 3 and 2 MVA and 1 MVA have been selected as backup in buses 7, 9, 3 and 9 in addition a single transaction taking place by the intertie of 1.4927 MVA and the dispatched power by expanding substation is zero (we do not expand the substation). Cost of planning for this load model is 2% at this scenario, active losses 52%, and the reactive losses is 52% lesser than at first scenario. It is clear that by investing on DGs instead of purchase of power at higher

ISSN 2229-5518

prices, DISCO may reduce its consumers' bill due to decrease in cost. Table 3 shows detailed results which are obtained for other load models in Scenario B.

DG, as a key element in DSP problem, is not used only to minimize planning cost and reduced active and reactive losses, but as it discussed, it also has several economic, social and electrical advantages. Figures (1) – (5) show voltage profiles of distribution network buses for all load models in both manners.

TABLE 2
RESULTS OF SCENARIO A

Index	Constant	Residential	Industrial	Commercial	Mixture
J (M$)	31.3837	24.0529	26.7622	21.1386	25.0651
S_{int} (MVA)	4.7820	2.9595	2.2405	4.9024	3.3959
$S_{i,u}$ (MVA)	9.7132	7.6799	9.8189	4.1953	7.7625
P_L (MW)	3.06	2.55	2.74	2.36	2.63
Q_L (MVAr)	2.14	1.78	1.92	1.65	1.84
NL	1	1	1	1	1

TABLE 3
RESULTS OF SCENARIO B

Index	Constant	Residential	Industrial	Commercial	Mixture
J (M$)	30.7797	23.2452	26.0381	20.8633	24.7617
S_{int} (MVA)	1.4927	3.0012	0.889	4.7927	1.2087
$S_{i,u}$ (MVA)	0	0	0	0.8567	0
P_{LDG} (MW)	1.46	1.6	1.4	1.91	1.41
Q_{LDG} (MVAr)	1.02	1.12	0.98	1.34	0.98
S_{DG} (MVA)	2,3,4,4	4,4	2,4,2,3	4	3,2,4,1
DG Location	5,3,9,7	9,7	3,7,5,9	9	7,3,9,5
NL	0	0	0	0	0

Voltage profiles are very better for all load models in planning with DG than without it. Load models influence on solutions.

One of the other advantages of introducing DG to solve DSP problem has been shown in Figs (6) – (10). As it seen, feeders' power flow is decreased for all load models, as a result, system losses is reduced and at last, losses cost will be decreased. Also, this reduces the feeders' load and subsequently, it increases feeders' lifetime. Similarly, we have a chance to use the existing distribution network with no need to upgrading feeders for further load growth. It is again observed that load models influence on solutions. The solutions which are derived from different load models do not apply to other models.

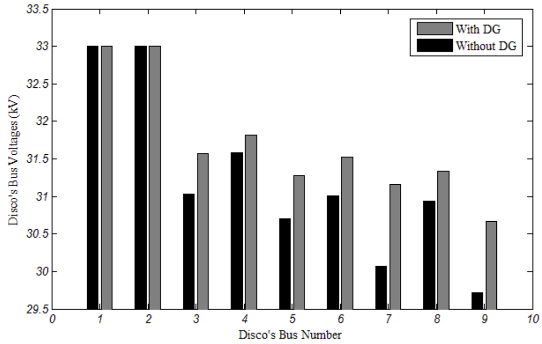

Fig. 1. DISCO's buses voltage profile for constant load model

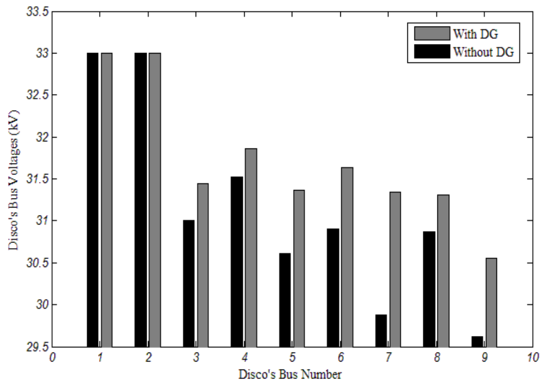

Fig. 2. DISCO's buses voltage profile for industrial load model

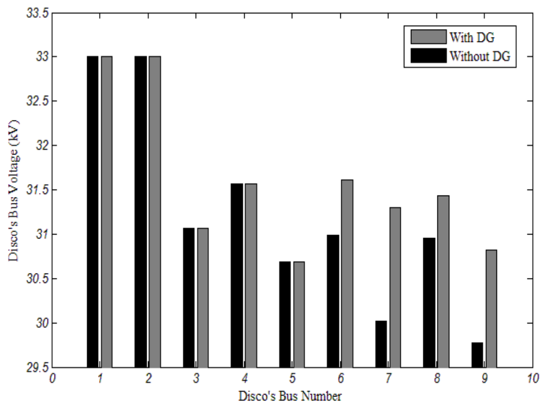

Fig. 3. DISCO's buses voltage profile for residential load model

ISSN 2229-5518

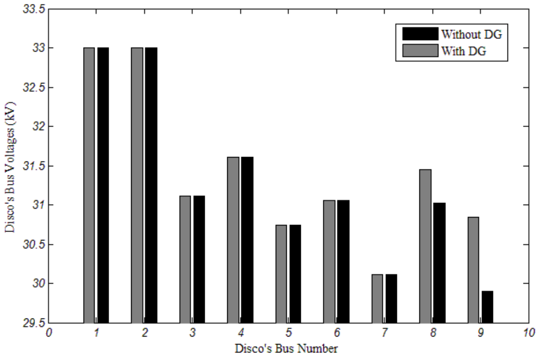

Fig. 4. DISCO's buses voltage profile for commercial load model

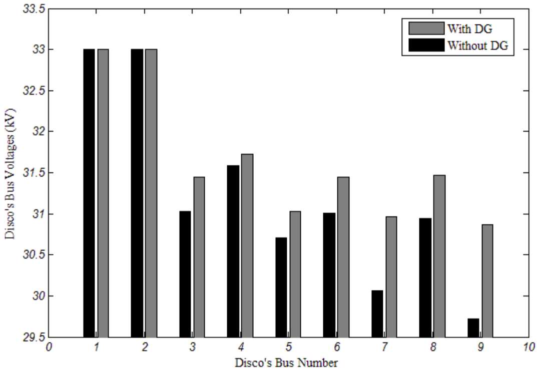

Fig. 5. DISCO's buses voltage profile for mixture load model

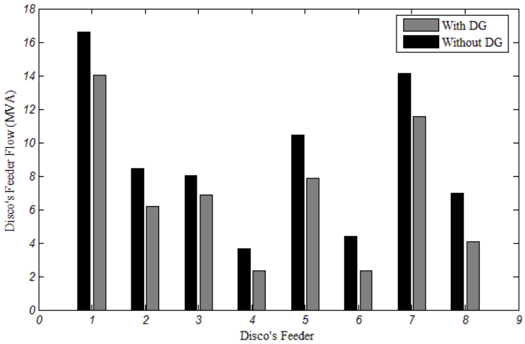

Fig. 6. DISCO's primary distribution feeder power flow for constant load model

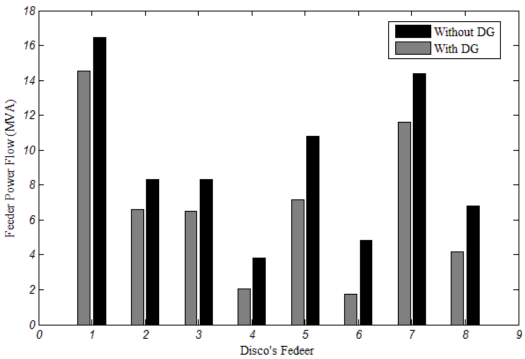

Fig. 7. DISCO's primary distribution feeder power flow for industrial load model

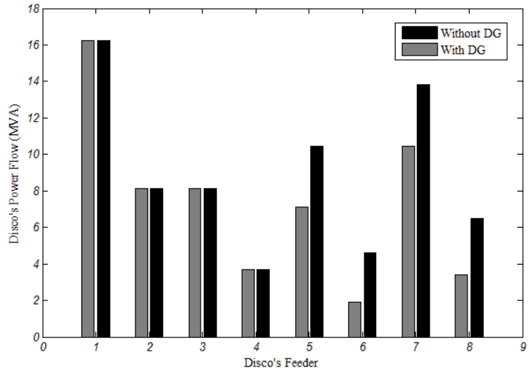

Fig. 8. DISCO's primary distribution feeder power flow for residential load model

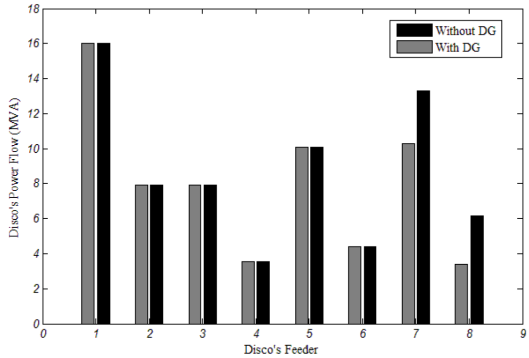

Fig. 9. DISCO's primary distribution feeder power flow for commercial load model

they are highly different from each other in cost values, losses, voltage profile and feeders' power flow, and this indicates that for an appropriate location-size planning, load models are important and crucial. As a new tool in solving DSP problem in comparison with traditional planning alternatives, investment on DGs may create further economic, social advantages. As a result, DISCO may restore its own customers and prevents these customers not to buy electricity power from other companies.

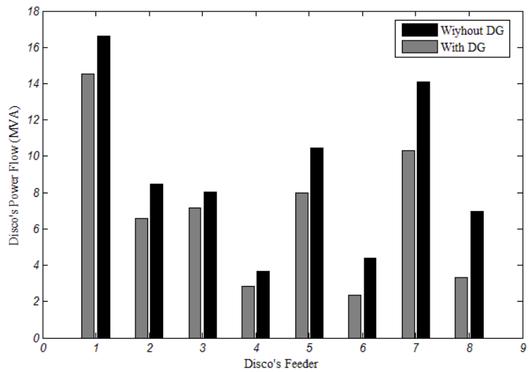

Fig. 10. DISCO's primary distribution feeder power flow for mixture load model

4 Conclusion

A comprehensive analysis was presented for DG location-size planning multiobjective optimization, including load models, in distribution systems. It was seen that when load models are considered, some changes occur in DG location and size. To estimate DGs optimal location and size, a new advanced optimization model was used. The proposed optimization model adapts cost, system total losses, voltage profiles and feeders' power flow and gives optimal answer which varied upon change of load models. The output results of this model not only give DG location and size, but also express a need to cost in order to purchase other new equipments (transformers and feeders upgrading). Based on information and rates that used at this paper, we observed that DG may lower planning cost, improve voltage profile of distribution system, decrease feeders' power flow of distribution networks, and minimize losses in distribution system and increase their lifetime by lower down feeders' load. Thus, DG gives an opportunity to use the existing distribution network to further load growth with no need to upgrade feeders.

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