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DG allocation with application of dynamic programming for loss reduction and reliability improvement

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ABSTRACT

Distribution system companies intend to supply electricity to its customers in an economical and reliable manner whereas customers in most distribution system are outspread and connect to distribution system with different type of equipments. These equipment usually have various types and resistance together, that produce highest loss and lowest reliability for distribution systems and customers that are not appreciated in networks. Distributed generations (DGs) are one of the best reliable solutions for these problems if they are allocated appropriately in the distribution system. This paper presents multi-objective function to determine the optimal locations to place DGs in distribution system to minimize power loss of the system and enhance reliability improvement and voltage profile. Time varying load is applied in this optimization to reach pragmatic results meanwhile all of the study and their requirement are based on cost/benefit forms. Finally to solve this multi-objective problem a novel approach based on dynamic programming is used. The proposed methodology is successfully applied to a study case and simulation results are reported to verify the proposed approach.

1. Introduction

Distribution system planners endeavor to supply economical and reliable electricity to customers. It is important to design, operate and maintain reliable power systems with lowest cost and highest benefit. Reliability improvement and loss reduction are two important goals for electrical distribution companies. These companies follow, consider and test a lot of technologies, optimization programs, etc. to bring above economic benefits and provide electricity with high quality and reliability and prevent interruptions in system because cost of interruptions and power outages can result severe economic impact on utility and customers.

With recent advances in technology, use of distributed generation (DG) in the power distribution system can provide the most economical solution and keep network in proper situation. A lot of Papers and studies have been carried out in recent years to present methodologies in DG placement and sizing.

One of the criteria to search the optimal DG allocation is minimizing power loss or reliability improvement.

Several papers have been published that address the use of artificial intelligence algorithms, analytical approaches or load flow approaches to optimize DG placement [1–12] based on minimizing power loss. Authors in [1,2] solve the problem by analytical approach [3], employs non-linear programming [4], uses combination of genetic algorithm and simulated annealing [5,6], present genetic algorithm [7], submits tabu search method and [8] uses fuzzy approach for optimization of its algorithm [9,10], apply load flow approaches [11], uses sequential optimization and [12] uses heuristic approach.

All papers presented in [1–12] deal important problems and weaknesses that are listed on below mentioned clauses:

- All the simulations performed in [1–12] address a static load condition. Objective function optimization based on a single load point, such as the peak load, may not provide reliable results.
- Reliability aspects in above mentioned papers are not considered while applying DGs to a distribution system can contribute to improving system reliability.
- DG placement in network has not been considered with evaluating reliability and loss at the same time.

Also some papers have appreciated approaches in their methodologies like [13], but considering static load condition in their concepts may not lead to satisfactory results.

This paper tries to overcome above mentioned weakness and proposes a novel algorithm to optimize objective function. To follow this proper purpose, first time-varying loads are taken into

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account then multi-objective function are considered based on a cost/benefit form that enhance benefits of DG allocation in system to compensate system loss, system reliability and cost of purchased power from transmission line along the planning period. Finally; to solve this multi-objective problem a novel approach based on dynamic programming is used. In addition DGs are considered as constant power source such as photo cells, fuel cells or gas generators. Also in this paper, purchased active power price from transmission grid varies in different time of day and also cost of energy not supplied for different customers (residential, commercial and industrial) varies in different time of the day.

In the following sections, load modeling is presented in Section 2, mathematical formulation is explained in Section 3, and objective function is submitted in Section 4, dynamic programming method is illustrated in Section 5 and a case study is reported in Section 6. Finally, the conclusions of the paper are summarized in Section 7.

2. Load modeling

Accurate optimization of objective function is resulted based on input data and correct analysis of this data. One important data is definition of load pattern. Distribution system load varies in different time of day, therefore in this paper, load condition is considered in three stages (light, medium and peak load). Passed time in these three stages is registered and maximum load consumption in each load point is considered as input data for DG allocation algorithm.

Table 1 shows abbreviations of above mentioned descriptions.

"A" parameter in second column of Table 1 presents percentage of minimum load to maximum load of network and other parameters present situations of the network.

Table 1
Load characteristic levels.

Load level (J)	Percentage of peak load (%)	Network condition	Passing time (h/year)
1	A–B	Light load	T_1
2	B–C	Medium load	T_2
3	C-100	Peak load	T_3

3. Mathematical model formulation

In this section, economical benefits and DG application costs are submitted and modeled. In this modeling, distributions system companies are responsible for providing customer demand, DG operation and distribution system management. All of these responsibilities are based on cost reduction and improving quality and reliability of customer service. Therefore costs and benefits of DG allocation in network can be expressed as follows.

3.1. DG costs evaluation

3.1.1. Investment cost

The cost of DG unit, investigation fee, site preparing for DG installation, construction, monitoring equipment, etc. are included in investment cost. These costs can be formulated as following equation.

$$C_1 = \sum_{i=1}^{\mathrm{NDG}} \sum_{K=1}^{\mathrm{KDG}} \mathrm{Cost}_{\mathrm{inv},iK} \tag{1}$$

3.1.2. Maintenance cost

Another yearly cost of DG allocation relates to maintenance cost. Maintenance cost includes annual mechanical and electrical inquiry and renovation cost. This cost is not related to placement of DG and is equal for all DG placements. This cost can be evaluated by:

$$C_2 = \sum_{i=1}^{\mathrm{NDG}} \sum_{k=1}^{\mathrm{KDG}} \mathrm{Cost}_{\mathrm{main},ik} \tag{2}$$

Present worth value of this annual cost with considering inflation rate and interest rate [14] in planning period is calculated below:

$$\mathrm{CPV}(C_2) = C_2 \sum_{t=1}^{T} \left(\frac{1+\mathrm{InfR}}{1+\mathrm{IntR}} \right)^t \tag{3}$$

3.1.3. Operation cost of DG

Since distributed generation shall trace load demands therefore it is required to have cost for its input source hence operation cost is equivalent to fuel cost. This cost and its present worth value are evaluated by:

$$C_3 = \sum_{i=1}^{\mathrm{NDG}} \sum_{k=1}^{\mathrm{KDG}} T_{\mathrm{J}} * \mathrm{DG}_{\mathrm{J},ik} * \mathrm{CG}_{ik} \tag{4}$$

$$\mathrm{CPV}(C_3) = C_3 \sum_{t=1}^{T} \left(\frac{1+\mathrm{InfR}}{1+\mathrm{IntR}} \right)^t \tag{5}$$

where N_{DG}: number of DG unit installed in network; K_{DG}: capacity of DG from 1 to 5 MW; $\mathrm{Cost}_{\mathrm{inv}}$: investment cost of DG sources ($/MW); $\mathrm{Cost}_{\mathrm{main}}$: maintenance cost of DG ($/MW-year); $\mathrm{DG}_{\mathrm{J},ik}$: Generated power by DG source installed in network in identified load level (MW); CG_{ik}: operation cost of DG sources ($/MW h); IntR: the interest rate; InfR: the inflation rate; CPV(): cost present worth; T_{J}: passing time (h/year)

3.2. DG benefits evaluation

3.2.1. Active power demand reduction from transmission line

In power system restructuring, electric utility distribution company purchases its power demand from transmission grid. Portion of this power demand is for distribution system customers and another one is spent in line and equipment loss. This power demand is evaluated by:

$$\mathrm{PT}_{\mathrm{NDG,J}} = \mathrm{PD}_{\mathrm{J}} + \mathrm{Loss}_{\mathrm{NDG,J}} \tag{6}$$

Distribution Company can supply portion of its power demand with considering DG in network and gets lower electric power from transmission grid. In this case electric power demand is calculated as below:

$$\mathrm{PT}_{\mathrm{DG,J}} = \sum_{i=1}^{\mathrm{NDG}} \sum_{k=1}^{\mathrm{KDG}} \sum_{L=1}^{\mathrm{Nloc}} \left(\mathrm{PD}_{\mathrm{J}} - \mathrm{DG}_{\mathrm{J},ik} + \mathrm{Loss}_{\mathrm{J},ikl}^{\mathrm{DG}} \right) \tag{7}$$

Therefore reduction of active power demand can be formulated as following equation:

$$\begin{aligned} \Delta\mathrm{PT} &= \mathrm{PT}_{\mathrm{NDG,J}} - \mathrm{PT}_{\mathrm{DG,J}} \\ &= \mathrm{Loss}_{\mathrm{NDG,J}} + \sum_{i=1}^{\mathrm{NDG}} \sum_{k=1}^{\mathrm{KDG}} \sum_{L=1}^{\mathrm{Nloc}} \left(\mathrm{DG}_{\mathrm{J},ik} - \mathrm{Loss}_{\mathrm{J},ikl}^{\mathrm{DG}} \right) \end{aligned} \tag{8}$$

And loss reduction based on presence of DG is evaluated by:

$$\Delta\mathrm{Loss}_{\mathrm{J},ikl} = \sum_{i=1}^{\mathrm{NDG}} \sum_{k=1}^{\mathrm{KDG}} \sum_{L=1}^{\mathrm{Nloc}} \left(\mathrm{Loss}_{\mathrm{NDG,J}} - \mathrm{Loss}_{\mathrm{J},ikl}^{\mathrm{DG}} \right) \tag{9}$$

Therefore Eq. (8) can be formulated as following equation:

$$\Delta\mathrm{PT} = \mathrm{PT}_{\mathrm{NDG,J}} - \mathrm{PT}_{\mathrm{DG,J}} = \mathrm{DG}_{\mathrm{J},ik} + \Delta\mathrm{Loss}_{\mathrm{J},ikl} \tag{10}$$

Based on above mentioned notes, active power reduction benefit for each year that Distribution Company can achieve is evaluated by:

$$B_1 = \sum_{J=1}^{3} C_{\mathrm{MWh,J}} * \Delta\mathrm{PT} * T_{\mathrm{J}} \tag{11}$$

Present worth value of (11) is calculated below:

$$\mathrm{BPV}(B_1) = B_1 \sum_{t=1}^{T} \left(\frac{1+\mathrm{InfR}}{1+\mathrm{IntR}}\right)^{t} \tag{12}$$

where BPV (): benefit present worth; $\mathrm{PT}_{\mathrm{NDG,J}}$: active power demand when not considering DG in network (MW); PD_{J}: customer active power demand (MW); $\mathrm{Loss}_{\mathrm{NDG,J}}$: system loss when not considering DG in network (MW); $\mathrm{PT}_{\mathrm{DG,J}}$: active power demand when considering DG in network (MW); $\mathrm{Loss}^{\mathrm{DG}}_{\mathrm{J},ikl}$: system loss when considering DG in network (MW); $C_{\mathrm{MWh,J}}$: energy market price in load level J ($/MW h).

It shall be noted that active power price is variant in different hours. This paper uses multi-level model for electricity price that is function of active power receiving from transmission grid. Fig. 1 shows the proposed electric price.

3.2.2. Reliability improvement

Some of reliability indices are fundamentally important but they do not always give a complete representation of system behavior and response. In order to submit the importance of a system outage, energy not supplied index (ENS) is evaluated. This index reflects total energy not supplied by the system due to faults during study period. This reliability analysis is implemented by analytical approach [15]. Therefore service disruption cost can be evaluated by using (13) which evolved out of [15] as below:

$$C_{\mathrm{ENS}} = \left[\sum_{b=1}^{\mathrm{Nb}} C_{\mathrm{int,J}} * \lambda_{\mathrm{b}} * L_{\mathrm{b}} * \left(\sum_{\mathrm{res}=1}^{\mathrm{Nres}} P_{\mathrm{res}} t_{\mathrm{res}} + \sum_{\mathrm{rep}=1}^{\mathrm{Nrep}} P_{\mathrm{rep}} t_{\mathrm{rep}}\right)\right] + C_{\mathrm{Equip,J}} \tag{13}$$

This point shall be noted that Eq. (13) can be used for ENS calculation with and without presence of DG in network.

If DG is sited in distribution system, it is used as alternative source to restore power to part of the loads that are failed based on faults on transmission grid and distribution system and system reliability is improved therefore reliability enhancement benefit for each year that Distribution Company can reach is expressed by Eq. (14):

$$B_2 = C_{\mathrm{ENS}} - C_{\mathrm{ENS,DG}} \tag{14}$$

Present worth value of (14) is calculated below:

$$\mathrm{BPV}(B_2) = B_2 \sum_{t=1}^{T} \left(\frac{1+\mathrm{InfR}}{1+\mathrm{IntR}}\right)^{t} \tag{15}$$

where N_{b}: number of branches in the network; λ_{b}: branches failure rate (f/km-year); L_{b}: branch length (km); $C_{\mathrm{int,J}}$: price of energy not supply in load level J. ($/MW h); N_{res}: number of nodes isolated during fault location; N_{rep}: number of nodes isolated during fault repair; P_{res}: loads are restored during fault; P_{rep}: loads are not restored during fault; t_{res}: duration of the fault location and switching time; t_{rep}: duration of the fault repair; $C_{\mathrm{Equip,J}}$: cost of energy not supply based on failure in equipments except of branches ($); C_{ENS}: cost of energy not supply without DG ($); $C_{\mathrm{ENS,DG}}$: cost of energy not supply with DG ($).

It shall be noted that price of energy not supply is not equal for different customer and different time of the day [16]. In this paper load points are divided into three groups: residential loads, commercial loads and industrial loads. Fig. 2 presents how price of energy not supply is calculated in this study.

4. Objective function

In conclusion, cost and benefit view points which have been described in previous sections are considered in one unique objective function that formulated below:

$$\begin{aligned} \mathrm{Max}\ Z &= \mathrm{Benefits} - \mathrm{Costs} \\ &= \mathrm{BPV}(B_1) + \mathrm{BPV}(B_2) - [C_1 + \mathrm{CPV}(C_2) + \mathrm{CPV}(C_3)] \end{aligned} \tag{16}$$

Therefore, distributed generation allocation problem can be solved by using dynamic programming which is appropriate optimization technique for the proposed function.

Given function shall be optimized considering below constrains.

- Voltage limits

Optimization shall be done in order to find out network nodes where DG can be installed and voltage profile is in the standard limits (i.e. 0.9–1.1PU) or in recovering case close to it.

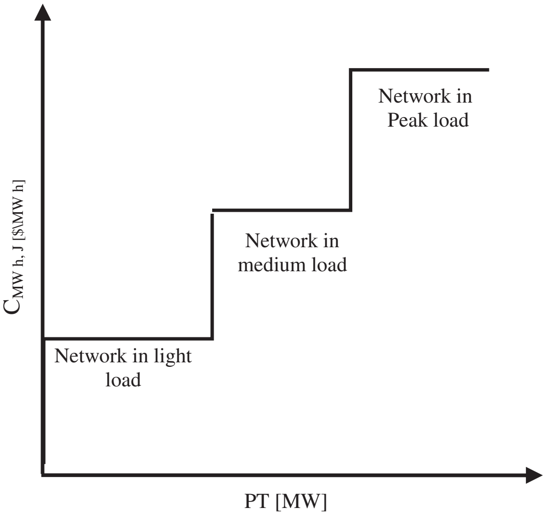

Fig. 1. Electricity price of transmission grid.

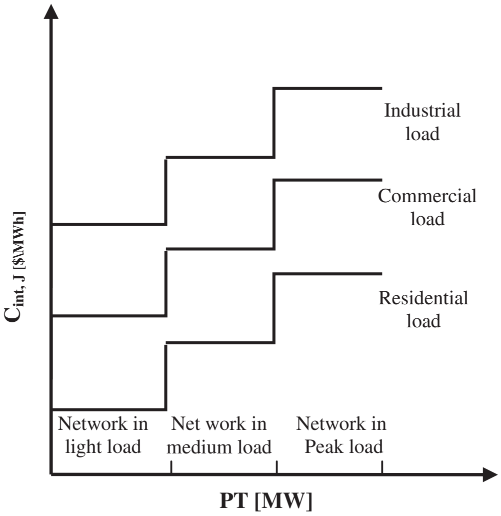

Fig. 2. Estimation of energy not supply price in network.

$$V_{\min} < V_{ij} < V_{\max} \tag{17}$$

where V_{ij} is the voltage of bus "i" in load level j.

- Capacity of feeders

Maximum flowing power at network feeders shall be limited to tolerance of conductors.

$$S_{ij} < S_{\max\ i} \tag{18}$$

where S_{ij} is the power flow at feeder "i" in load level j; $S_{\max\ i}$ is maximum flowing power at feeder "i".

- Maximum capacity of installed DGs at network

Total installed capacity of distributed generations is limited by following constrain:

$$\sum_{i=1}^{\mathrm{NDG}} \sum_{k=1}^{\mathrm{KDG}} \mathrm{DG}_{\mathrm{J},ik} < \mathrm{DG}_{\mathrm{J},\max} \tag{19}$$

where $\mathrm{DG}_{\mathrm{J},\max}$ is maximum capacity of DG in load level j.

4.1. Calculation of variables and indices

Calculation of objective function variables, which has been derived from reliability and power loss indices of the network, is the main part of optimization problem. There are different methods and software for calculation of reliability and power loss. In this paper, for calculation of power loss, Mat Power application of MATLAB software with load flow capability has been used with minor modification and for calculation of reliability index; analytical method which has been programmed in Microsoft Excel has been used.

5. Dynamic programming

At most practical problems, sequential applications shall be proceed in different time for solving a problem. Problems which shall be solved by sequential decisions are named sequential decision problem. Dynamic programming in one kind of multi-stages sequential decision problem which is an efficient mathematical method for study and optimization of multi-stages sequential decision making problems [17].

5.1. Optimization algorithm

The major steps of the algorithm are:

- Problem will be divided into stages. For each stage, a decision policy will be required. In the other hand, each stage indicates a part of problem which needs required decision. Number of stages in DG allocation problems equals number of candidate locations for DG installation. Decision making methods at each stage includes loss reduction and reliability improvement.
- Each stage contains related states. In current research, number of distributed generations with specified capacity that can be allotted to mentioned stages, will be considered as state of the problem.
- In each stage, current state of the stage will be transferred to related state in next stage by making a decision.
- Autonomous policy for the remained stages can be followed by knowing current state. Totally for optimization with dynamic programming, current state information transfers all required information for previous behaviors which will be required for identification optimized policy from current state to the next.
- Problem will be solved by finding optimized policy for each state from the last state which named backward solution. Response to this stage is evident because process will be pursued from destination.
- Optimized policy for all states of stage "n" can be determined by a backward function and by assuming that optimized policy for all "$n + 1$" stages has been defined.
- Solution will be applied by using backward function from one stage to previous stage running from end. In each stage, optimized policy for all states of that stage will be specified and finally optimized policy for first stage will be determined.

$$f_n(S_n, X_n) = Z_n(X_n) + f^*_{n+1}(S_n - X_n) \tag{20}$$

$$f_n(S_n, X_n) = Z_n(X_n) + \mathrm{Max} \sum_{L=n+1}^{\mathrm{Nloc}} Z_L(X_l)$$

$$f^*_n(S_n) = \mathrm{Max}\, f_n(S_n, X_n) \quad \text{and} \quad \sum_{L=n+1}^{\mathrm{Nloc}} X_l = S_n$$

where S_n: are states of stage n; f^*_{n+1} optimized value of function in stage $n + 1$; X_n decision at stage n.

Proposed algorithm based on dynamic programming for DG placement has been accomplished by programming with MATLAB application and it is extendable for different distribution network.

The general diagram of the algorithm that follows for DG allocation is shown in Fig. 3.

6. Case study

Test system for case study has been shown in Fig. 4 [18]. For testing of proposed technique, distributed generations have been considered as negative loads, 1–5 MW, 0.9 lag power factors. Distribution test network includes high voltage distribution substation 132–33 kV which feeds eight load points and each branch has been separated from network by an isolator switch. Maximum capacity of each branch of the network is 25 MV A. Network daily active loads has been shown in Fig. 5. Power factor of all points is 0.9 lag and all load points of the network has been considered as candidate for installation of DG.

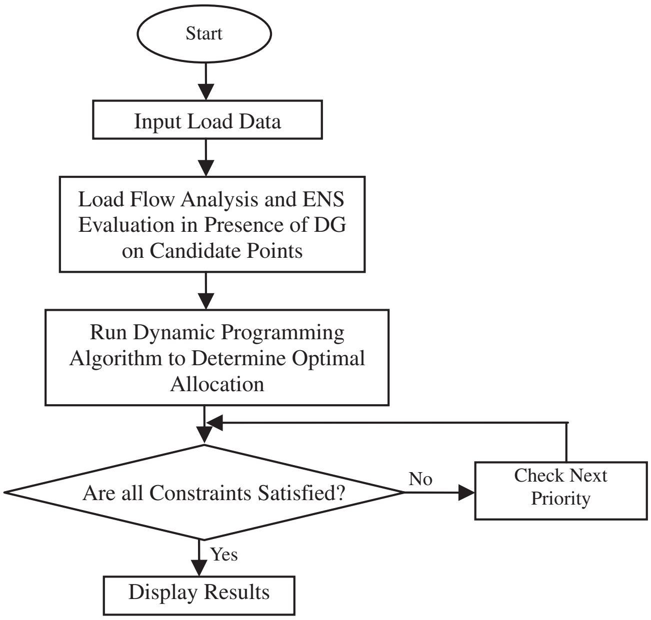

Fig. 3. Optimal DG allocation methodology.

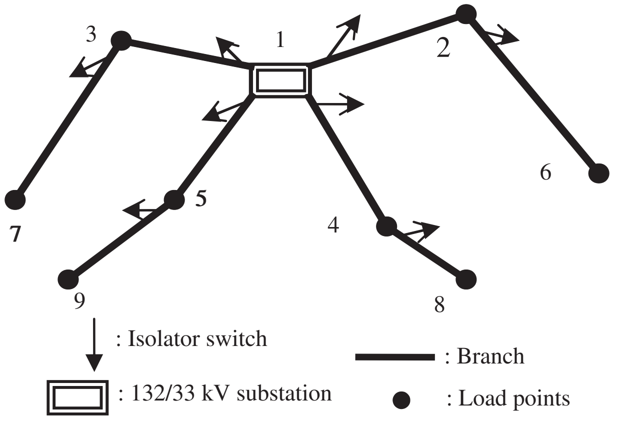

Fig. 4. Studied test network.

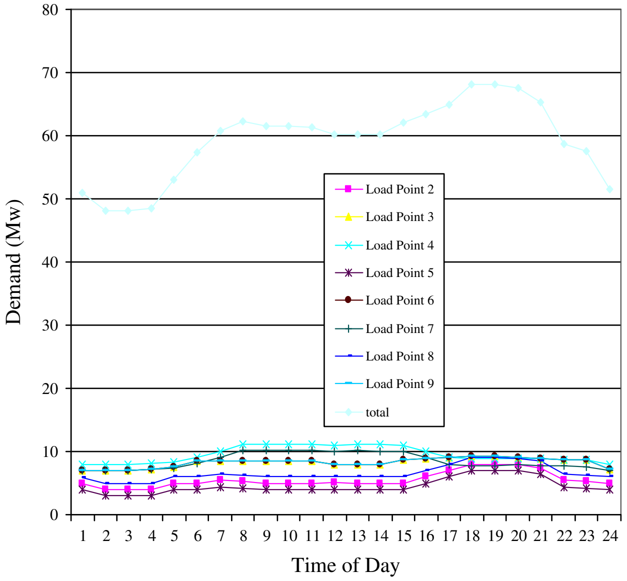

Fig. 5. Curve of daily demands for high voltage distribution substation and eight load points.

In this study, fault rate for 33 kV overhead lines, is 0.046 (f/km-year) and for high voltage distribution substation 132/33 kV is 0.05 f/year and all other devices of the network has been considered to be 100% reliable. Maintenance time for overhead lines is 8 h and for high voltage distribution substation is 15 h. Time for fault location and isolating faulted zone and connection of DG to the network has been considered 1 h [19]. In addition, price of energy not supply based on load type and network condition has been mentioned in Table 2.

Table 2
Required information for reliability evaluation.

Load points	Load type	Network situation	Price of not supplied energy ($/kW h)
2, 3, 6	Residential	Light load	0.053
		Medium load	0.073
		Peak load	0.105
4, 7, 8, 9	Commercial	Light load	2
		Medium load	2.8
		Peak load	3.6
5	Industrial	Light load	6
		medium load	8.4
		Peak load	11.050

Technical information of the test network and loads in three levels has been shown in Table 3. Minimum and maximum loads of the network are 48.15 and 68.2 MW, respectively. Therefore load demands of the network in this study changes from 70.6% to 100% of the peak load.

Cost of purchased active power from transmission system in specified level has been mentioned in Table 4. Time of network being in three position light load, medium load and peak load will be specified from the load curve which has been shown in Fig. 5. Information for active load during 24 h of the day has been modeled. In other hand, these curves indicate daily loading of the system during whole year. For modeling of annual load change, these curves have been repeated 365 times.

In addition, commercial information regarding DGs has been specified in Table 5 that evolved out of [14,18].

6.1. Numerical studies and results analysis

Table 6 has been resulted from simulation based on effect of DG allocation on optimization of power loss and reliability of the system. In this table first column in each condition of the network refers to loss reduction point of view and acquired benefit during planning period. Second column in each condition of the network refers to best location and size of DG from improvement of reliability view point and its profit based on DG efficient in planning period that has been exchanged to present worth.

Study results obtained from first column of light load (from loss reduction point of view in DG allocation) shows that there is 0.584 MW decrease in loss which is equal to 1278.96 MW h/year

Table 3
Technical characteristics of branches and load data.

Section		R (Ω)	X (Ω)	Length of branch (km)	Max. load in level 1 (MW)	Max load in level 2 (MW)	Max load in level 3 (MW)
From	To						
1	3	1.4	1.5	1.5	5	6	8
3	7	2.78	5.5	5.5	7.5	8.8	9.2
1	2	2	4	4	8.3	11.2	9
2	6	2.8	5.5	5.5	4	5	7
1	5	1.7	1.7	1.7	7.5	8.8	9.2
5	9	2.1	4	4	7.3	10.2	8
1	4	2.26	4.5	4.5	6	7	9
4	8	2.4	5	5	7.5	8.7	9.2

Table 4
Technical and commercial information.

Level	Percentage of peak load	Network situation	Time duration (h/year)	Market price ($/MW h)
1	70.6–80	Light load	2190	35
2	80–95	Medium load	4745	49
3	95–100	Peak load	1825	70

Table 5
Commercial information of DGs.

Parameter	Unit	Value
DG investment cost	$/MW	318,000
DG operation cost	$/MW h	29
DG maintenance cost	$/MW h	7
Interest rate	%	12.5
Inflation rate	%	9
Planning period (DG life time)	Year	20

Table 6
Profit analysis from studied viewpoints.

Network condition	Peak load		Medium load		Light load	
DG allocation	From loss reduction point of view	From reliability point of view	From loss reduction point of view	From reliability point of view	From loss reduction point of view	From reliability point of view
	2 MW at node 6 3 MW at node 8	1 MW at node 5 4 MW at node 8	2 MW at node 6 1 MW at node 7 2 MW at node 8	1 MW at node 5 4 MW at node 8	2 MW at node 6 1 MW at node 7 2 MW at node 8	5 MW at node 8
Benefit of loss reduction ($)	1,685,881	1,404,571	2,792,897	2,259,740	679,784	571,531
Benefit of reliability improvement ($)	358,797	587,431	237,525	456,890	169,669	326,349
Total benefits ($)	2,044,678	1,992,008	3,030,422	2,716,630	849,453	897,880

and 679,784$ benefit acquired during DG life time. In addition, profit due to reliability improvement of the network for DG locating in order to reducing loss is 169,669$. From first column of mid loading condition it is concluded for DG placement from loss reduction viewpoint, there is 0.791 MW decrease in loss of the system that equal to 3753.3 MW h/year and its present worth is 2792,897$. Moreover profit due to reliability enhancement of the network is 237,525$. For peak loading condition, loss will be lessen 0.869 MW which is equal to 1585.93 MW h/year considering peak loading interval which is worth 1685,881$ for DG life time and benefit for reliability improvement is 358,797$.

From second column of light loading, it can be seen 0.491 MW will be reduced from loss of the network which is equal to 1075.29 MW h/year considering light load interval by DG allocation for reliability improvement. Then present worth of this energy in DG life time equals 571,531$. In the same condition during mid load, loss reduction is 0.64 MW which is equal to 3036.8 MW h/year and its worth is 225,9740$ for DG life time. During heavy loading, loss will be decreased to 0.724 MW, multiplying to heavy loading duration it is equal to 1321.3 MW h/year. Then present worth is 1,404,577$.

It is worth mentioning that for allotted capacity to three conditions, distribution companies will purchase less power from transmission grid then related profit during DG life time shall be considered too. Benefit regarding this condition has been summarized in Table 7.

The remained problem is to calculate investment, maintenance and operation costs of distributed generations for the three conditions of loading. These costs considering commercial information of Table 5 has been shown in Table 8 for planning period.

At last, net benefit resulted of allocation DG based on proposed objective function in accordance with equation (16) shall be computed. This profit considering benefit of optimized DG allocation minus total costs from Tables 6 to 8 can be expressed in Table 9.

According to results presented in Table 9, in light loading condition optimized DG allocation emphasizing on reliability improvement approaches more benefit comparing to loss reduction effort. In this condition optimization constrains are in appropriate range which has been shown in Figs. 6 and 7. In mid loading condition, loss reduction view point achieves more benefit to distribution companies and as it can be seen from Figs. 8 and 9, there is improvement in voltage profile and reduction on power flowing in the feeders. In peak load condition, network condition is similar to mid loading and constrains are in suitable range which can be seen in Figs. 10 and 11.

Table 7
Reduction in purchased energy from transmission network.

Network condition	Reduction in purchased energy (MW h/year)	Benefit ($)
Light load	10,950	5,820,073
Medium load	23,725	17,654,221
Peak load	9125	9,700,122

Table 8
Economical costs for DG allocation in the network.

Economical costs	Network condition	DG operation (MW h/year)	Costs ($)
Investment Operation Maintenance Total	Low load	10,950	1,590,000 4,822,346 116,401 6,528,747
Investment Operation Maintenance Total	Medium load	23,725	1,590,000 10,448,416 252,203 12,290,619
Investment Operation Maintenance Total	Peak load	9125	1,590,000 4,018,622 97,001 5,705,623

Table 9
Net benefit resulted in study case.

Network condition	Peak load	Medium load	Light load
Net benefit ($)	6,039,177	8,394,026	189,207
DG allocation view point	Loss reduction	Loss reduction	Reliability improvement

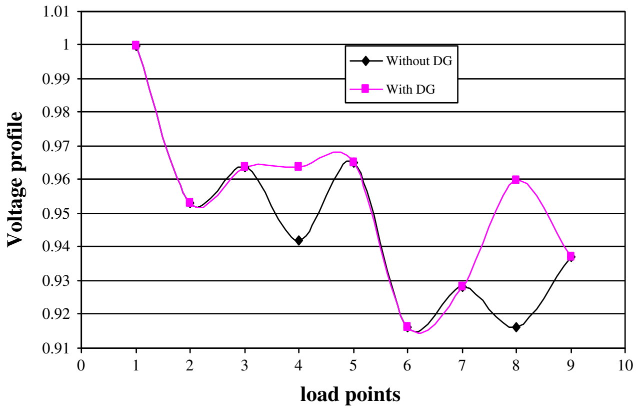

Fig. 6. Voltage profile in light load.

Finally, for comparing benefits of proposed approach with other settled methodologies, two papers [14,20] have been considered with the same case study but DGs have been located and sized on network with different methodologies and concepts.

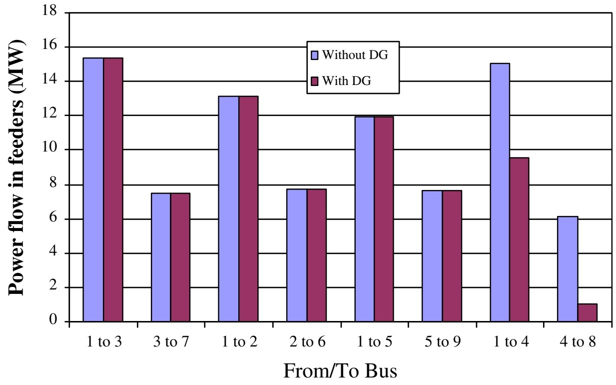

Fig. 7. Power flow in feeders in light load.

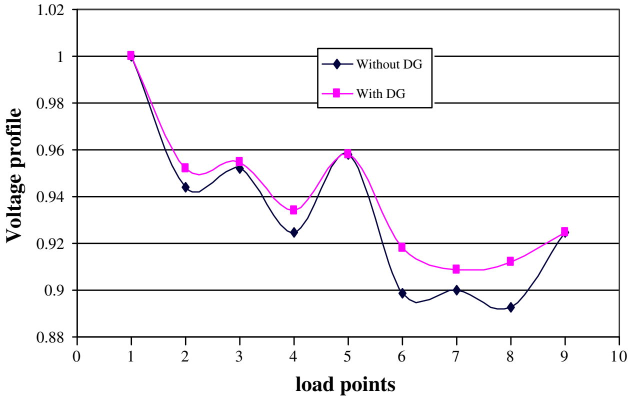

Fig. 8. Voltage profile in medium load.

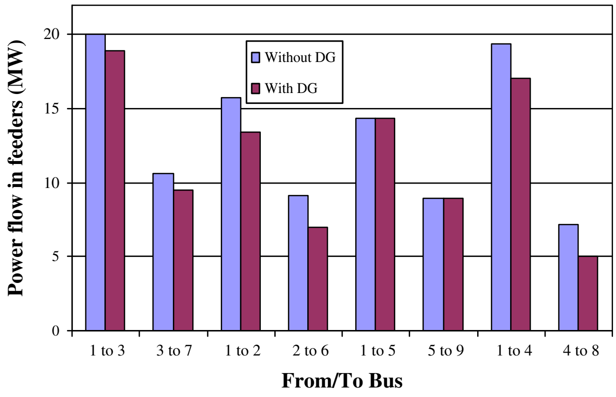

Fig. 9. Power flow in feeders in medium load.

But it shall be noted that reliability assessment and its benefits for reliability improvement has not been studied on those papers. Moreover, since cost dada in two mentioned papers have minor differences with respect to this paper therefore they can be compared just on loss reduction point of view.

Table 10 compares percentage of loss reduction and total capacity of DGs on network with these papers.

Authors in [14] have estimated and located about 20 MW DGs in network hence costs of investment, maintenance and operation of DGs are increased by enhancement on DGs capacity which can decrease final benefits. In addition, DGs are not located in light load of network because costs of DGs are higher than their benefits therefore loss has not been reduced in this network condition but this matter can be removed in case of considering benefits of reliability improvements in presence of DGs in the system. This paper by considering 1/4 of total DG capacity compared with [14] can reduce optimized amount of losses and attain remarkable benefits.

Authors in [20] in case of DG versus substation expansion (planner decision) have settled DGs in distribution system with 18 MV A capacity which is about 3.5 times of total DG capacity in respect of this paper but important problem is that all analysis and calculations in [20] is based on peak load condition and other situations

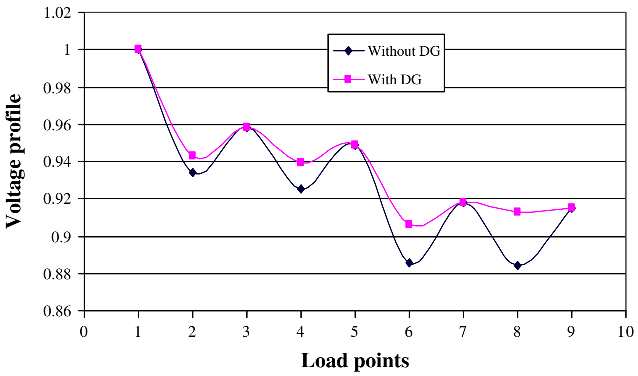

Fig. 10. Voltage profile in peak load.

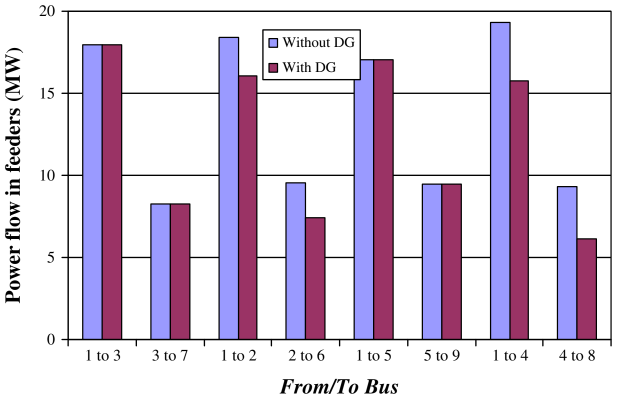

Fig. 11. Power flow in feeders in peak load.

Table 10
Results comparison.

Methodology	Network condition	Total capacity of DGs to network (MW)	Loss reduction after DG installation (%)
Proposed approach	Light load	5	24.5
	Medium load	5	21.5
	Peak load	5	21.2
Ant colony optimization [14]	Light load	0	0
	Medium load	19	43.1
	Peak load	20	36.8
Comprehensive optimization model and planners experience [20]	Peak load	18 MV A	53.6

of network conditions have not been considered and another problem is that authors have not applied reliability benefits in objective function of problem.

But this point shall be considered that over increasing of distributed generation total capacity in network that has been regarded in [14,20], may not have significant effects on the transmission system, but its impacts at the lower voltage distribution system could be important particularly in respect of fault current levels, the magnitude and direction power flow, the system voltage (both steady-state and transient) and the system stability under various small and large signal transient conditions. These impacts and interactions may be having negative impacts on the distribution network operating characteristics.

7. Conclusions

In this paper, introducing dynamic programming as an optimization tool, a novel method has been presented to find best location for distributed generation installation in the network with variable load model which results maximum profit. Load of the network has been modeled in different level and the problem has been optimized considering existed constrains on permanent operation of the distribution system. From studied results it has been derived that reliability and loss of the network are drastically depends on location of the consumer, demanded power of the network, type and capacity of the distributed generations and their location in the network. In addition network condition have great effects on DG allocation in system.

DG allocation has another advantage in addition to mentioned benefits which cannot be neglected. These beneficial effects include improvement in voltage profile of the load point and locating network buses in allowable limit. Another advantage is reducing of power flow in feeders because of compensating loss and part of required power of load points of the network. It decrease stress of the feeders especially feeders that they are next to high voltage distribution substation. This increases duration of life time of the equipment.

Therefore DGs can get technical and financial benefits as indicated in simulation results if allocated in proper locations with appropriate sizes.

In future works there are extra considerations that must be careful attention about network upgrading problem and reduction of purchased reactive power in presence of DG in network. This mentioned factors may affect the results of DG allocation.

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