Long Term Optimal DG Placement Considering Transmission System Reliability and Load Uncertainty

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ABSTRACT:
DG (dispersed generation) application has received increasing attention during recent years. The impact of DG on various aspects of distribution system characteristics depends highly on DG location in distribution feeder. This paper presents an optimization method to determine long term optimal DG placement in distribution systems in which system reliability and operational constraints as well as environmental constraints are taken into account. In order to get more realistic results impact of load uncertainty is modeled using normal distribution function. Furthermore, DG transactions with the market and corresponding payoffs are calculated. Despite, most of studies dealing with the problem from cost minimization point of view in a short term period, here DG placement is investigated from long term perspective. To get more accurate results the model considers both DG benefits and costs and the objective function is based on DG profit maximization. Benefits of using DG consist of loss reduction revenue, reducing in costumers' interruption costs, power purchase saving as well as green house gas and fossil fuel reductions. Whereas, the costs consist of initial costs, maintenance and operating costs and DG transition costs as well. The proposed model is simulated on a standard IEEE test system to obtain the results and show the accuracy of the model.

KEYWORDS: Dispersed generation, Optimal placement, Profit, Load Uncertainty, Reliability, Power market

1. INTRODUCTION

The technical challenges associated with the DG can be subdivided into three categories, planning and design, DG interconnection (system interface to the grid) and operation and control of DG [1]. This paper focuses on the first category. Application of DG in distribution network can lead to considerable reliability enhancement, loss reduction, power cost saving and using less fossil fueled power plants thereupon reduce the amounts of greenhouse gases. In contrast, power quality issue, islanding operation and voltage control problems are among troublesome impacts of DG application [2].

The impact of DG on system operation depends highly on DG location in distribution system such that installing DG on improper locations would lead to increase in energy loss and loading of distribution feeders. For this reason, an optimization method must be used to find optimal DG location.

In recent decade, a large amount of research and literature have been accomplished on DG placement with different methods. In [3] ACO algorithm is used to find DG location and size for minimization costs consist of losses cost. Ref [4] attempts to find DG location using fuzzy approach with goal of minimizing system losses and DG costs. In [5] Gandomkar et al employ an algorithm based on integrating the use of genetic algorithm and simulated annealing methods for optimal allocation of DG. Celli et al in [6] suggest a multi objective approach based on the non-dominated sorting genetic algorithm to locate DGs. In [7] authors apply a priority-ordered constrained search technique for optimal DG allocation and minimize overall power losses. In [8] and [9] an analytical approach is applied to short term DG placement with loss minimization target. In [10] authors demonstrate radial based function (RBF) neural network that provides an optimal placement of DGs for power system loss reduction and voltage profile enhancement. In [11], Sookanata et al apply particle swarm optimization (PSO) technique to optimal placement of DG in order to minimize line losses of the radial distribution network. Hejazy et al in [12] propose a multi-objective differential evolution algorithm for sizing and sitting of DG units in distribution feeders, for simultaneous minimization of system costs, loss and energy purchased from outside. In [13], authors suggest the artificial bee colony (ABC) algorithm to determine the optimal size, location and power factor of DG to minimize total system real power loss. In [14] authors apply Hereford ranch algorithm for optimal placement of DGs in order to minimize the loss of network. In [15], authors suggest an optimization methodology which is based on the sequential quadratic programming (SQP) algorithm for determining DG size and location to reach a certain level of loss reduction with the minimum DG cost. El-Khattam et al in [16] use a heuristic approach to find optimal DG size and location in distribution feeders from an investment point of view. Ameli et al in [17] propose the fuzzy logic with full search to determine the allocation of DG for voltage profile improvement and loss reduction in distribution network. In [18] authors suggest a there step procedure based on genetic algorithm and decision theory to establish the best DG sitting and sizing on distribution network considering technical constraints. Most of these literatures are based on short term planning.

In this paper, an optimization method is proposed to determine long term optimal DG placement in which system reliability and operational constraints as well as environmental constraints are taken into account. In order to get more realistic results impact of load uncertainty is modeled using normal distribution function. Furthermore, DG transactions with the market and corresponding payoffs are calculated. Unlike, most of prior researches dealing with the problem from cost minimization point of view in a short term period, here DG placement is investigated from long term perspective. To get more accurate results the model considers both DG benefits and costs and the objective function is based on DG profit maximization.

Benefits of using DG consist of loss reduction revenue, reducing in costumers' interruption costs, power purchase saving as well as green house gas and fossil fuel reductions. Whereas, the costs consist of initial costs, maintenance and operating costs and DG transition costs as well. Dynamic programming is employed to find DG optimal locations for 10 years planning period. The proposed model is simulated on a standard IEEE test system to obtain the results and show the accuracy of the model. The paper is represented as follows: In section 2 the problem formulation is proposed. In section 3 optimization method is introduced. Section 4 presents a model for uncertainty in load. Section 5 represents the case study and finally conclusion is provided in section 6.

2. PROBLEM FORMULATION

In this section the proposed formulation for long term optimal DG placement is presented. At first all relevant benefits and costs due to DG application are introduced. Accordingly, an optimization model is proposed for long term optimal DG placements in which system reliability and security indices are taken into account.

2.1. DG Benefits Calculation

DG benefits for each year (8760 hours) are calculated from these factors:

1. Loss cost reduction (ΔCLoss)
2. Power purchase saving (PPS)
3. Load point interruption cost reduction (ΔLPIC)
4. Greenhouse gas cost reduction
5. Fossil fuel cost reduction

$$\text{Benefit}_{DG} = \sum_{i=1}^{N_{DG}} \sum_{j=1}^{N_{year}} (\Delta CLoss_{ij} + PPS_{ij} + \Delta LPIC_{ij}) \qquad (1)$$

Where:

N_{DG}: Number of DG units

N_{year}: Number of years in the study period

N_{loc}: Number of candidate locations for DG installations

2.1.1. ΔCLoss (Loss Cost Reduction)

Since occasionally DGs are installed at the load points they may have an important role in loss cost reductions. Nevertheless, during maintenance period DGs are not able to deliver energy to the system. On the other hand, in long term studies the impacts of economic and monetary parameters are unavoidable. Here in order to increase the accuracy effect of banking interest rate (IR) is considered.

Consequently, the amount of loss reduction revenue due to DG application can be calculated as follow:

$$\Delta CLoss_{ijk} = \sum_{i=1}^{N_{DG}} \sum_{j=1}^{N_{year}} (\Delta Loss_{ijk} \times EP_j \times (1+IR)) \qquad (2)$$

$$\Delta Loss_{ijk} = \left(\frac{365 - \mathbf{Dmain}}{365}\right)(Loss_{old} - Loss_{ijk}) + \frac{\mathbf{Dmain}}{365}(Loss_{old}) \qquad (3)$$

Where,

$\Delta Loss_{ijk}$: Loss reduction due to using DG *i* in year *j* in place (k) (kwh)

$Loss_{old}$: Annual energy loss without DG application (kwh)

$Loss_{ijk}$: Annual energy loss when DG applied (kwh)

EP_j : Energy price in year *j* (c/kwh)

D_{main}: DG maintenance outage days

IR : Interest rate (%)

Note that during maintenance outage days, DG is not able to contribute and to reduce the costs.

2.1.2. PPS (Power Purchase Saving)

DG owners may benefit from self-producing in terms of not purchasing the power from the grid. Considering annual DG generations and energy price for each year the aggregated power purchase saving will be derived as below:

$$PPS_{ij} = \sum_{i=1}^{N_{DG}} (ADG_i \times EP_j) \qquad (4)$$

Where:
ADGi : Annual generation of DG (i) (kwh)
Here, for more realistic study impact of yearly inflation rate is considered on energy price as shown in Eq. (5).

$$EP_j = EP_0 \times (1+IF)^{j-1} \quad (5)$$

IF : Inflation rate (%)
EP_0 : Initial value of energy price

2.1.3. ΔLPIC (Load Point Interruption Cost Reduction)

From system reliability point of view one of the main advantages of using DG is reducing load point interruptions. Hence, system operator may benefit from reducing in load point interruption costs. Assuming these interruption costs in presence and absence of DGs, Eq. (6) illustrates the obtained revenue emerging from LPIC.

$$\Delta LPIC_{ijk} = \left(\frac{365-\mathbf{Dmain}}{365}\right)(LPIC_{old}-LPIC_{ijk}) + \frac{\mathbf{Dmain}}{365}(LPIC_{old}) \quad (6)$$

$LPIC_{old}$: Annual load point interruption cost without DG application ($)
$LPIC_{ijk}$: Annual load point interruption cost when DG applied ($)
LPIC might be calculating according to network specifications such as fault occurrence rate of branches as shown in Eq (7):

$$LPIC = \sum_{i=1}^{nlb} \sum_{j=1}^{nbr} (P^f_{ij}.L_j.\lambda.T.C_{ue}) \quad (7)$$

Where P^f_{ij} is value of power not supplied in *ith* bus due to fault occurrence in *jth* branch as shown in Eq. (8).

$$P^f_{ij} = \sum_{k\in\psi_j} \sigma_k [D_k - \sum_{x\in\varphi} p_{DG,kx}] \quad (8)$$

In which:
σ_k:Load shedding coefficient for fault occurrence in bus k
D_k : Power demand in bus k
$p_{DG,kx}$: Capacity of xth DG located in bus k
φ: The set of DGs participating in load relief
ψ_j : The set of islanding points after fault occurrence in line j
L_j and T are length of jth branch and average time duration for fault occurrence, respectively. λ is fault occurrence rate in each kilometer of branch and C_{ue} is unit cost of energy not supplied. Eventually, nlb and nbr are number of load busses and number of branches, respectively. Similarly, DG is not able to contribute and reduce costumers' interruption costs during maintenance outage days.

2.1.4.GHGR (Greenhouse gas reduction)

To reduce green house gas (GHG) emission using less fossil fueled power plants, pollution not emanated can be considered as an appropriate objective function to encourage distribution companies (DisCo) or independent power producers (IPP) towards using clean or renewable technologies [19]. This may be interpreted as the cost saving of pollution not generated due to utilization of clean DG units. For this purpose a pollution rate is used for each technology of DG units.

$$GHGR = (DG^{cap}.\alpha . EPR - \sum_{i=1}^{N_{DG}}(EDG_i)).PC.(1+IR).8760 \quad (9)$$

$$DG^{cap} = \sum_{i=1}^{N_{DG}}(P_{DGi}) \quad (10)$$

$$EDG_i = \sum_{j\in tech}(P_{DGi} \times ER_j) \quad (11)$$

where,
DG^{cap} : Total capacity of DG units (kw)
α: Average plant factor of integrated power plant in grid (%)
ERP: Emission average rate of integrated fueled power plants (kg/kwh)
EDG_i: Total emission of DG *i* (kg/kwh)
PC: Social cost of pollution ($/kg)
P_{DGi}: capacity of DG *i* (kw)
ER_j: Emission rate of *j* th DG technology (kg/kwh)

2.1.5. Fossil fuel reduction

One of the advantages of DG units in CHP operation mode is the primary energy saving. This advantage can be considered as an incentive policy by system regulator to promote these technologies among system. For this purpose, heat to electricity rate (HTER) for CHP technologies is used as indicated in Eq. (12) to model this incentive.

$$CHPR = \sum_{i=1}^{N_{DG}} \sum_{j\in tech} (P_{DGij} .\alpha_j .HTER_j .C_h)(1+IR) \quad (12)$$

Where,
$HTER_j$: Heat to electricity rate of j th CHP technology.
C_h: Heat price
α_j :Generating average factor of jth technology of DG
This feature can be considered as a benefit for system operator to avoid fossil fuel consumption for heat generation.

2.2. DG Costs Calculation

Besides DG revenues there are some costs related to DG owners such as initial costs of DG installations, maintenance and operating costs. In addition due to long term study there may be an additional cost due to DG probable transition. Therefore, the DG cost model may consist of several individual costs as illustrated in Eq. (13).

$$Cost_{DG} = \sum_{i=1}^{N_{DG}}(IC_i) + \sum_{i=1}^{N_{DG}} \sum_{j=1}^{N_{year}}(OC_{ij} + MC_{ij} + TC_{ij}) \quad (13)$$

IC_i: Initial cost of DG *i* ($)
OC_{ij}: Operation cost of DG *i* in year *j* ($)
MC_{ij}: Maintenance cost of DG *i* in year *j* ($)
TC_{ij}: Transition cost of DG *i* at the beginning of year *j* ($)

2.2.1. Initial And Operation Costs

Initial cost includes DG procurement and installation costs. On the other hand DG operation cost depends on DG annual generation as well as corresponding costs as indicated in Eq. (14)

$$OC_{ij}= ADG_i \times FC_j \times TE \quad (14)$$

FC_j: Fuel cost in year *j* ($)
TE: Thermal efficiency (Mbtu/kwh)
OC_{ij}: Operation cost of DG *i* in year *j* ($)

2.2.2.Maintenance Cost

DG maintenance cost consists of repair cost and lost DG revenue during maintenance outage. Similarly, impact of inflation rate can be modeled in DG maintenance cost using initial costs.

$$MC_{ij}= MC_{i0} \times (1+IF)^{j-1} \quad (15)$$

MC_{i0}: Initial cost for DG *i* ($)
MC_{ij}: Maintenance cost of DG *i* in year *j* ($)

2.2.3. Transition cost

DG transition cost is composed of two parts representing cost of DG displacement from point K at the end of year (j-1) to point K' at the beginning of year j ($DC_{ikk'}$) and cost of DG lost revenue during displacement (LDG), respectively. Therefore, DG transition cost is shown as Eq. (16).

$$TC_{ij}= DC_{ikk'} + LDG_{ij} \quad (16)$$

In which DG lost revenue during displacement is as below:

$$LDG_{ij}= (h_{trans} \times P_{DGi} \times EP_j \times (1+IR)) \quad (17)$$

In Eq. (16) P_{DGi} is generation output of DG(i) and h_{trans} is DG displacement duration (in hour).

Based on relevant DG benefits and costs the objective function of DG owner or system operator for a long term optimal DG placement is based on maximization of DG profit that is difference between corresponding benefits and costs as below:

$$Max\ Profit= Benefit_{DG} - Cost_{DG} \quad (18)$$

Subject to:

$$P_{DGi}-P_{Li}= \sum_{j\in i} P_{ij} \quad (19)$$

$$P_{ijmin} < P_{ij} < P_{ijmax} \quad (20)$$

$$\sum_{i=1}^{N_{DG}} (P_{DGi})= P_{Loss} + \sum_{i=1}^{N_L} (P_{Li}) \quad (21)$$

$$V_{imin} < V_i < V_{imax} \quad (22)$$

Where:
N_L: Number of consumers
P_{ij} : Power flow in line between buses *i* and *j*
$P_{ijmax(min)}$: Maximum (minimum) capacity of line *ij*
P_{Li} : Load consumption in bus *i*
V_i: Voltage magnitude in bus *i*
$V_{imax(min)}$: Maximum (minimum) voltage magnitude level
P_{Loss}: Power system loss

In above equations, Benefit $_{DG}$ and Cost $_{DG}$ refer to DG aggregated benefits and costs as mentioned before. Eq. (19) shows the load balance at each node. Eq. (20) represents maximum and minimum power flow capacities in each line. System load balance is illustrated in Eq. (21) and eventually bus voltage marginal limits are provided in Eq. (22).

3. Optimization Technique

Considering proposed long term model appropriate optimization tools should be employed to get the optimum results over a long period of time. Consequently, a forward Dynamic Programming (DP) approach is used in this study to solve the optimal DG placement problem.

The optimization is accomplished based on annual peak loads. For more realistic study it is assumed that there exists an annual load growth,(*a*). Consequently, the peak load associated with each year is as Eq. (23):

$$P_{Lj} =P_{Ljo} \times (1+a)^{j-1} \quad (23)$$

Where:
P_{Ljo}: Initial peak load
P_{Lj}: Peak load in year *j*

Employing forward DP method and considering inflation in DG annual costs and benefits with DG portability, all of the possible paths from first year to the 10th year are searched. Eventually, the path with the maximum highest profit is obtained as the optimum solution for DG placement over the considered time period. Both $Benefit_{DG}$ and $Cost_{DG}$ are determined as a matrix with dimension of $N_{state} \times N_{year}$ in which, N_{state} is the total states in each year and N_{year} is the number of years in desired period.

Considering number of candidate locations for DGs (N_{loc}) and number of existing DGs in the system (N_{DG}) the number of total states would be derived as Eq. (24):

$$N_{state} =N_{loc}^{\ N\ DG} \quad (24)$$

Therefore, the number of all searching paths is as below:

$$N_{path} =N_{state}^{\ N\ year} \quad (25)$$

Due to probable large number of DGs and candidate locations in a real electric system the search space may increase drastically. Therefore, some heuristic methodologies such as priority list should be employed to reduce the search space and hence the CPU runtime. For instance Fig.1 illustrates a reduced system with 5 states (N_{state} =NP =5) in which X is the allowed number of paths to be searched at each step (X=3).

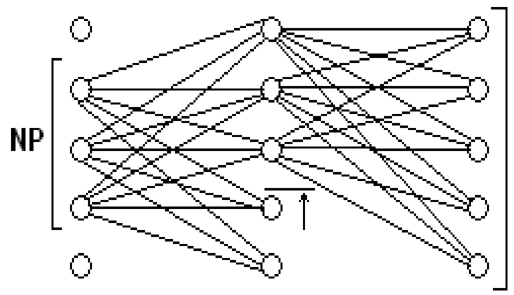

Fig. 1. Reducing technique for DP search space

4. Uncertainty of Load

It is interesting to incorporate the peak load uncertainty in the optimal DG placement problem. In a real study there are always some uncertainties in terms of load demand, energy price and etc. Therefore, distribution system studies may be affected by these uncertainties. One of the most significant factors that plays important role in optimal DG placement is load uncertainty. In order to deal with problem various probability distribution functions are employed. In this study, uncertainty in system peak load demand is modeled with a normal distribution function in which the mean value is equal to the forecasted peak load. The distribution is then divided into seven intervals as shown in Fig. 2.

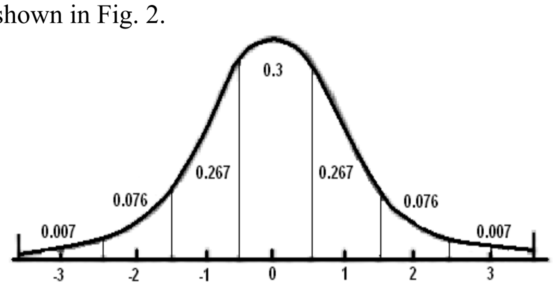

Fig. 2. Normal probability distribution function for load uncertainty

Here, horizontal axis is the interval number. The probability of each interval is also shown in Fig. 2 which is calculated using normal probability function. For each interval, the peak load is calculated as Eq. (26)

$$Peak_m = \mu \times (1 + m\sigma) \quad (26)$$

Where,

$Peak_m$: Peak load for interval *m*

m: Interval number

μ : Forecasted peak load for each year (mean value)

σ : Standard deviation of peak load uncertainty

In order to study the impact of load uncertainty on DG corresponding profits the above loading intervals are considered, assuming that the system peak load is equal to Eq. (26) for each interval. The relevant components are then calculated based on mathematical expectation ated probability of the interval as follow:

$$E(LPIC_{old,un}) = \sum_{m=1}^{7} (P_m \times LPIC_{old,,m}) \quad (27)$$

$$E(LPIC_{ijk,un}) = \sum_{m=1}^{7} (P_m \times LPIC_{ijk,,m}) \quad (28)$$

$$E(Loss_{old,un}) = \sum_{m=1}^{7} (P_m \times Loss_{old,,m}) \quad (29)$$

$$E(Loss_{ijk,un}) = \sum_{m=1}^{7} (P_m \times Loss_{ijk,,m}) \quad (30)$$

Where,

$LPIC_{old,m}$: Customer interruption cost before DG application for interval *m*

$LPIC_{ijk,m}$: Customer interruption cost with DG application for interval *m*

$E(LPIC_{old,un})$: Expectation of annual Customer interruption cost before DG application considering load uncertainty

$E(LPIC_{ijk,un})$: Expectation of annual customer interruption cost with DG application, considering load uncertainty

$Loss_{old,m}$: Energy loss before DG application for interval *m*

$Loss_{ijk,m}$: Energy loss with DG application for interval *m*

$E(Loss_{old,un})$: Expectation of annual energy loss before DG application considering load uncertainty

$E(Loss_{ijk,un})$: Expectation of annual energy loss with DG application considering load uncertainty

P_m : Probability of interval *m*

5. CASE STUDY

In this paper, DigSilent power system analysis software [20] is employed to solve the problem and obtain DG optimal placement. The proposed method is applied to distribution reliability test system (RTS). Fig. 3 demonstrates the single line diagram of this system. This test system is a radial 33/11kv power distribution system including four 33kv and eleven 11kv buses. The system provides the possibility of load transfer in case of contingencies. DG installation is possible in 11kv buses. The candidate buses are highlighted in Fig.3 with 1, 2, 3, and 4, respectively. One Diesel generator and one Micro turbine are available. DG generation capacity is 1.5 Mw for Diesel and 1 Mw for Micro turbine. The considered time horizon the study is 10 years.

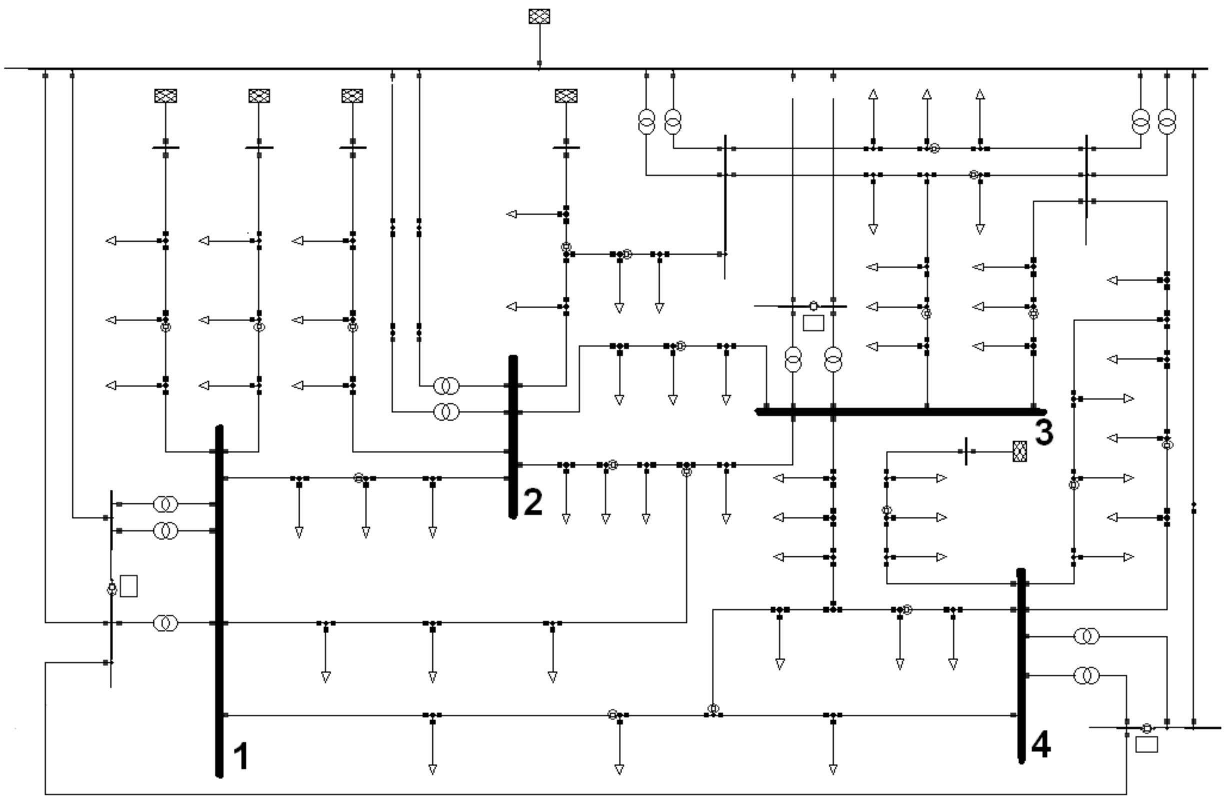

Fig .3. Single line of distribution test system

The numerical values of DG variables are shown in Table 1

Table 1. Numerical value required for optimization

Technology Variable	Diesel	Micro Turbine
IC($)	482000	510000
MC_0($)	25000	22000
h_{main}(hrs)	48	48
h_{trans}(hrs)	120	120
ER(kg/kwh)	0.65	0.72
α(%)	35	50
HTER	1.88	2.29

In which h_{main} is DG maintenance outage period in hour. EP_0 , IF and IR are assumed to be 8.5 c/kwh , 6% and 9% ,respectively. DG fuel costs are shown in Table.2 for a 10 years period.

Table 2.Fuel cost during desired period

Year	FC ($/Mbtu)
1 to 2	2.54
3 to7	2.61
8 to 10	2.74

Transition cost for diesel and microturbine are assumed to be 241000 $ and 255000 $, respectively. The simulation process is shown in the flowchart of Fig.4. Considering number of DGs and candidate points, optimal placement is carried out for a 10-year study period.

Table.3 shows the optimal placement results for 10 years study period when the load growth rates are assumed to be 2%, 6%, 10%, respectively. Here, constant loads with no uncertainty are assumed for system load points. As shown in this case there is no transition for DGs during 10 years. Subsequently, Table 4 shows the obtained values for aggregated PROFIT of solution associated with each load growth.

Based on considered energy prices and corresponding IF aggregated power purchase saving may be calculated.

Here, due to fixed DG capacity the amount of total PPS will be constant (16773147 $) over 10 years period of time that is included in DG aggregated profit. Although PPS is not an effective factor in DG allocations, however, in order to obtain DG real profit this part is considered in our study.

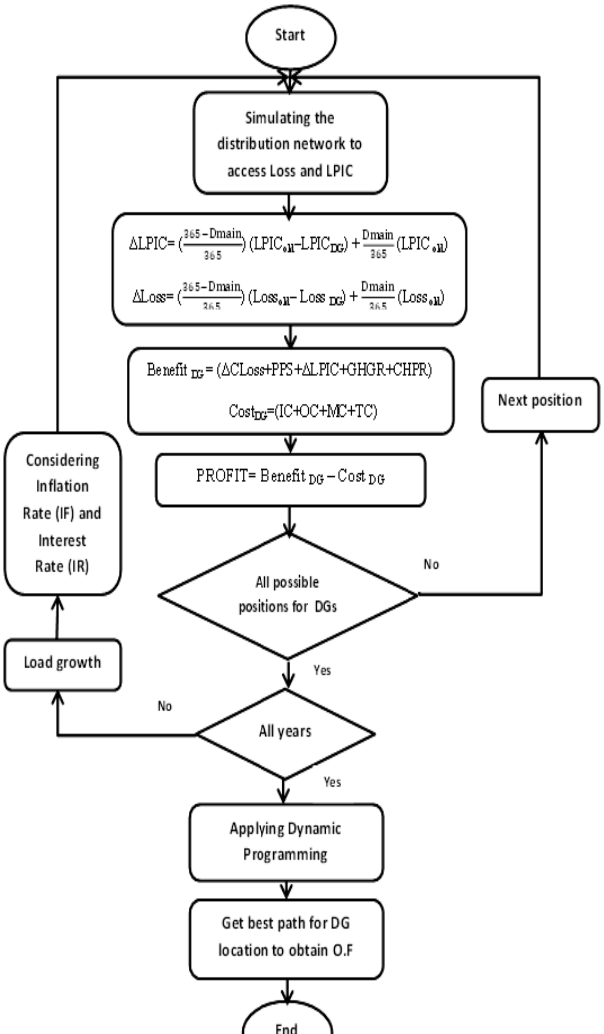

Fig. 4. Flowchart of proposed optimal DG location

Table 3. DG optimal placement with fixed load

Year	Diesel location			Microturbine location		
	a=2%	a=6%	a=10%	a=2%	a=6%	a=10%
1	4	4	4	2	2	2
2	4	4	4	2	2	2
3	4	4	4	2	2	2
4	4	4	4	2	2	2
5	4	4	4	2	2	2
6	4	4	4	2	2	2
7	4	4	4	2	2	2
8	4	4	4	2	2	2
9	4	4	4	2	2	2
10	4	4	4	2	2	2

Table 4. PROFIT values for all load growths with fixed load

Load growth	%2	%6	%10
PROFIT	26148371	30834682	37216883

Fig. 5 illustrates the variation in PROFIT during 10 years study period for each load growth rate.

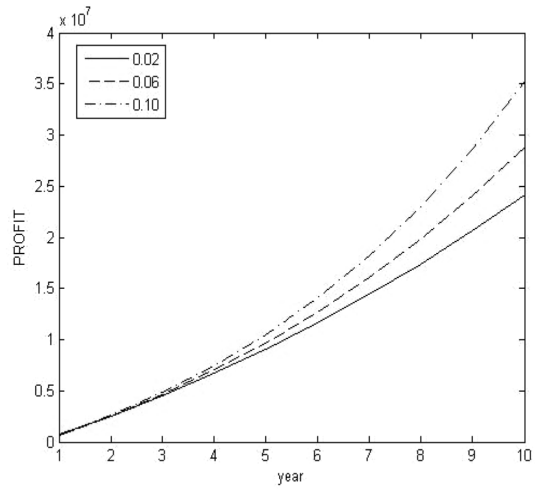

Fig. 5. PROFIT during 10 years

As expected increasing in load demand during 10 years results in increases in DG profit. It is due to more contribution of DGs in case of higher load demands. In addition the discrepancy of obtained profits is considerable among different load growths by approaching the 10^{th} year.

In order to consider the effect of load uncertainty (LU) on DG optimal locations, program is run considering a variable load with normal distribution function of σ=20%. The results of DG locations are shown in Table 5.

Table 5. DG optimal placement with LU (σ=20%)

Year	Diesel location			Microturbine location		
	a=2%	a=6%	a=10%	a=2%	a=6%	a=10%
1	4	4	4	2	4	4
2	4	4	4	2	4	4
3	4	4	4	2	4	4

4	4	4	4	2	4	4
5	4	4	4	2	4	4
6	4	4	4	2	4	4
7	4	4	4	2	4	4
8	4	4	4	2	4	4
9	4	4	4	2	4	4
10	4	4	4	2	4	4

In comparison with Table.3 it is seen that the microturbine must be moved from bus 2 to bus 4 in load growths 6% and 10%. Similarly, Table.6 shows the obtained values for profits associated with different load growth rates. Here, DG profits show slight increases in comparison with fixed load case in Table. 4. This is due to uncertainty nature of load that will bring about some decreases in DG aggregated costs.

Table 6. PROFIT values for all load growths with LU (σ=20%)

Load growth	%2	%6	%10
PROFIT	26179488	30870409	37274234

As stated environmental parameters in terms of greenhouse gas and fossil fuel reductions may be considered among advantages of employing DG when using as CHP. In this case these parameters have no interference in DG location, and only cause to increase in profit of DG application and could be considered as an objective function to encourage using clean or renewable technologies. In order to show the impact of these parameters on DG profits, Table 7. shows corresponding profits when environmental parameters are not taken into account.

Table 7. PROFIT values for all load growths without environmental benefits

Load growth	%2	%6	%10
PROFIT	24192168	28883089	35286914

DG transition costs may play an effective role in DG optimal locations. In order to study the impact of transition costs one can assume that there is no transition cost allocated to corresponding DGs. Table 8 shows optimal DG placements with no transition costs and load uncertainty of σ=20%.
Comparing Tables 5 and 8 it appears that DG placements are not changed for 2% load growth; however, for load growths of 6% and 10% the microturbine has shifted its location. Obviously it is due to relatively large amount of transition costs that increases DG aggregated costs. Hence, ignoring this cost may lead to more DG displacements over considered time horizon. Subsequently, Table 9 shows DG profits in case of absence of transitions costs. In 2% load growth DGs are not displaced hence there is no change in aggregated profits. However, due to neglecting transition costs corresponding DG profits are increased in 6% and 10% load growths.

Table 8. DG placement with LU (σ=20%) neglecting TC

Year	Diesel location			Microturbine location		
	a=2%	a=6%	a=10%	a=2%	a=6%	a=10%
1	4	4	4	2	2	2
2	4	4	4	2	2	2
3	4	4	4	2	2	2
4	4	4	4	2	2	4
5	4	4	4	2	4	4
6	4	4	4	2	4	4
7	4	4	4	2	4	4
8	4	4	4	2	4	4
9	4	4	4	2	4	4
10	4	4	4	2	4	4

Table 9. PROFIT values for all load growths neglecting TC

Load growth	%2	%6	%10
PROFIT	26179488	30934828	37318821

In order to consider the accuracy of proposed model one can obtain DG optimal locations as well as corresponding profits regardless of relative DG costs. For this purpose the problem is divided in two subproblems as follow.
Firstly, consider system aggregator entitled DG owner just deal with benefits regarding loss reduction revenues. In fact its objective function would be maximizing total revenues obtained from system loss reductions. Secondly, assume system aggregator may just benefit from reducing in load interruption costs. Hence, the corresponding objective function is maximizing total revenues obtained from load interruption cost reductions. Note that load uncertainty with σ=20% is considered for both subproblems. Furthermore, no cost in terms of transition and etc is included here.

Table 10. DG placement with LU (σ=20%) for MAX (ΔCLoss)

Year	Diesel location			Microturbine location		
	a=2%	a=6%	a=10%	a=2%	a=6%	a=10%
1	4	4	4	2	2	2
2	4	4	4	2	2	2

3	4	4	4	2	2	4
4	4	4	4	2	4	4
5	4	4	4	2	4	4
6	4	4	4	2	4	4
7	4	4	4	2	4	4
8	4	4	4	2	4	4
9	4	4	4	2	4	4
10	4	4	4	4	4	4

Tables 10 and 11 illustrate DG optimal locations in two above mentioned cases, respectively. Comparing Tables 8 and 10 it is seen that results are almost the same. It can be interpreted that the most effective parameter in DG placements is loss reduction revenues. However as indicated in Table 11, solely considering interruption cost reduction revenues, regardless of loss reduction revenues may lead to different results that necessarily are not the best choices. Note that DG transition cost is an important factor in long term DG optimal placements; hence, the obtained results may be inaccurate and unreliable.

Table 11. DG placement with LU (σ=20%) for MAX (ΔLPIC)

Year	Diesel location			Microturbine location		
		a=6%	a=10%	a=2%	a=6%	
	a=2%					a=10%
1	3	3	3	2	2	2
2	3	3	3	2	2	2
3	3	3	3	2	2	2
4	3	3	3	2	2	2
5	3	3	3	2	2	2
6	3	3	3	2	2	2
7	3	3	3	2	2	2
8	3	3	3	2	2	2
9	3	3	3	2	2	2
10	3	3	3	2	2	2

Finally, DG aggregated profits in different load growth rates are illustrated in Tables 12 and 13, respectively.

Table 12. DG loss reduction revenues for all load growths with MAX (ΔCLoss)

Load growth	%2	%6	%10
Revenue	16648988	21444636	27836020

Table 13. DG load interruption cost reduction revenues for all load growths with MAX (ΔLPIC)

Load growth	%2	%6	%10
Revenue	95921	115466	139615

Tables 12, 13 show reductions in DG related profits in comparison with prior mentioned studies. This is due to the fact that other DG revenues such as environmental benefits and power purchase savings are neglected. As shown in Table 13 DG loss reduction revenues play an important role in DG aggregated profits such that neglecting this term may lead to drastic reductions in DG benefits. Although DG costs are not considered in recent studies; nevertheless, due to their less effectiveness DG aggregated profits are diminished. Finally, it should be noted that due to large capacity of diesel generator and its strategic location that results in the least transmission loss the diesel placement is unchanged in all cases.

6. CONCLUSION

In this paper a heuristic optimization model is proposed for long term optimal DG placement in which system reliability and operational constraints as well as environmental constraints are taken into account. The model considers DG revenues from system reliability and environmental view points as well as DG costs in terms of maintenance, operating and transition costs. Dynamic programming is employed to find DG optimal locations for 10 years planning period. The method is applied to a distribution test system in which impact of various load growths in two cases, with and without load uncertainty is investigated. The results show that the amount of DG profits may vary due to different parameters such as load growths and load uncertainty as well. In addition, impact of environmental factors on DG optimal placements and relative profits are investigated and effect of transition cost on DG displacements is studied. Loss reduction revenue is introduced as the most effective parameter in DG optimal placements so that, solely considering interruption cost reduction revenues, regardless of loss reduction revenues may lead to different results that necessarily are not correct.

REFERENCES

[1] Marei MI, El-Saadany EF, SalamaMMA. 2002. **"Flexible distributed generation: (FDG),"** *IEEE Power EngSoc*. Summer Meet 1:49–53.

[2] Ahmadigorji, M., A. Abbaspour, A. Rajabi-Ghahnavieh. 2009. **"Optimal DG placement in distribution systems using cost/worth analysis,"***World Academy of Science, Engineering and Technology 49*.

[3] Falaghi, H. and M.R. Haghifam. 2007. **"ACO based algorithm for distributed generation sources allocation and sizing in distribution system,"** *Proceeding of IEEE Lausanne power Tech.* july 1-5. University Tehran. pp 555-560

[4] Haghifam, M.R., H. Falaghi and O.P. Malik. 2008. **"Risk-Based distributed generation placement,"** *IET Generation Transmission Distribution 2*:252-260

[5] Gandomkar, M., M. Vakilian and M. Ehsan. 2005. **"A combination of genetic algorithm and simulated annealing for optimal DG allocation in distribution networks,"** *CCECE/CCGEI. Saskatoon. IEEE.* PP.645-648.

[6] Celli, G., S. Mocci, F. Pilo, G.G. Soma. 2008**. "A Multi-Objective Approach for the Optimal Distributed Generation Allocation with Environmental Constraints Probabilistic Methods Applied to Power Systems,"** *PMAPS '08. Proceedings of the 10th International Conference on.* vol., no., pp.1-8, 25-29.

[7] Abu-Mouti, F.S. and M.E. El-Hawary. 2010. **"A priority-ordered constrained search technique for optimal distributed generation allocation in radial distribution feeder systems,"** *Electrical and Computer Engineering (CCECE) 23rd Canadian Conference on.* vol., no., pp.1-7, 2-5 May

[8] Acharya, N., P. Mahat and N. Mithulananthan. 2006. **"An analytical approach for DG allocation in primary distribution network,"** *Int. J. Electrical Power Energy Syst*., 28:669-678.

[9] Duong Quoc Hung, N. Mithulananthan, R.C. Bansal. 2010**. "Analytical Expressions for DG Allocation in Primary Distribution Networks,"** *Energy Conversion, IEEE Transactions on* . vol.25, no.3, pp.814-820, Sept.

[10] Qudaih, Y.S., Syafaruddin and T. Hiyama. 2010. **"Conventional and Intelligent Methods for DG Placement Strategies,"** *Power and Energy Engineering Conference (APPEEC)*. Asia-Pacific , vol., no., pp.1-4, 28-31 March

[11] Sookananta, B., W. Kuanprab, S. Hanak. 2010. **"Determination of the optimal location and sizing of Distributed Generation using Particle Swarm Optimization,"** *Electrical Engineering / Electronics Computer Telecommunications and Information Technology (ECTI-CON), International Conference on.* vol., no., pp.818-822, 19-21 May.

[12] Hejazi, H.A., M.A. Hejazi, G.B. Gharehpetian, M. Abedi. 2010. **"Distributed generation site and size allocation through a techno economical multi-objective Differential Evolution Algorithm,"** *Power and Energy (PECon) IEEE International Conference on* , vol., no., pp.874-879, Nov.

[13] Abu-Mouti, F.S. and M.E. El-Hawary. 2009. **"Modified artificial bee colony algorithm for optimal distributed generation sizing and allocation in distribution systems,"** *Electrical Power & Energy Conference (EPEC) IEEE* , vol., no., pp.1-9, 22-23 Oct.

[14] Gandomkar, M., M. Vakilian, M. Ehsan. 2005. **"Optimal distributed generation allocation in distribution network using Hereford Ranch algorithm,"** *Electrical Machines and Systems, ICEMS. Proceedings of the Eighth International Conference on.* vol.2, no., pp.916-918 Vol. 2, 29-29 Sept.

[15] Le, A.D.T., M.A. Kashem. M. Negnevitsky, G. Ledwich. 2007. **"Optimal Distributed Generation Parameters for Reducing Losses with Economic Consideration,"** *Power Engineering Society General Meeting. IEEE* , vol., no., pp.1-8, 24-28 June

[16] El-Khattam, W., K. Bhattacharya, Y. Hegazy M.M.A. Salama. 2004. **"Optimal investment planning for distributed generation in a competitive electricity market,"** *Power Systems, IEEE Transactions on* , vol.19, no.3, pp. 1674- 1684, Aug.

[17] Ameli, M.T., V. Shokri, S. Shokri. 2010. **"Using Fuzzy Logic & Full Search for Distributed generation allocation to reduce losses and improve voltage profile,"** *Computer Information Systems and Industrial Management Applications (CISIM), International Conference on* , vol., no., pp.626-630, 8-10 Oct.

[18] Carpinelli, G., G. Celli, F. Pilo and A. Russo. 2001. **"Distributed generation siting and sizing under uncertainty,"***Power Tech Proceedings, IEEE Porto* , vol.4, no., pp.7 pp. vol.4.

[19] Zanganeh. A, Sh. Jadid, A. Rahimi-Kian. 2010. **"Uncertainty based distributed generation expansion planning in electricity markets,"** *Springer.ElectrEng* 91:369-382

[20] Digsilent, Power System Calculation Package, (2007) *Available: http://www.Digsilent.de/softwar*