Multi-Objective Fuzzy Model in Optimal Siting and Sizing of DG for Loss Reduction

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***Abstract*—**This paper presents a possibilistic (fuzzy) model in optimal siting and sizing of Distributed Generation (DG) for loss reduction and improve voltage profile in power distribution system. Multi-objective problem is developed in two phases. In the first one, the set of non-dominated planning solutions is obtained (with respect to the objective functions of fuzzy economic cost, and exposure) using genetic algorithm. In the second phase, one solution of the set of non-dominated solutions is selected as optimal solution, using a suitable max-min approach. This method can be determined operation-mode (PV or PQ) of DG. Because of considering load uncertainty in this paper, it can be obtained realistic results. The whole process of this method has been implemented in the MATLAB7 environment with technical and economic consideration for loss reduction and voltage profile improvement. Through numerical example the validity of the proposed method is verified.

***Keywords*—**Fuzzy Power Flow, DG siting and sizing, Load Uncertainty, Multi-objective Possibilistic Model.

I. INTRODUCTION

DISTRBUTED Generation (DG) is not a new concept. If one looks back on the evolution of the electric power industry, electricity was introduce as an attractive alterative for steam, hydraulics, direct heating and cooling which were produced near the point of consumption in a small scale. The main idea behind the DG is that generation is small scale, which can be easily placed closer to the point of consumption. Distributed and dispersed generators are, by definition, small size generators, which can come from traditional or some revolutionary technologies. The planning of the electric system with the presence of DG requires the definition several factors, such as: the best technology to be used, the number and the capacity of the units, the best location, the network connection way, etc. The impact of DG in system operating characteristics, such as electric losses, voltage profile, reliability, among other, needs to be appropriately evaluated.

The optimum planning of power distribution networks is one of the most important research fields for electrical engineers. That is because of the close proximity of these networks to the ultimate consumers and of their great length, which has as a consequence increased capital investment and increased operational costs because of their losses. Distribution system planner must ensure that there is adequate substation capacity and feeder capacity to meet the load growth within the planning horizon year. The ultimate aim of this research is to plan distribution networks which satisfy the growing demand for electricity, fulfill specific technical operational constraints and which are also characterized by the minimum overall cost (investment and operational cost).

The problem of DG allocation and sizing is of great importance. The installation of DG units at non-optimal places can result in an increase in system losses, implying in an increase in costs and, therefore, having an effect opposite to the desired.

When planning electricity distribution networks, a part of the data used in the calculations is more or less uncertain [2]. The loads vary with time and it is not possible to predict an exact value for the peak load of a certain year.

Fuzzy set theory offers a way to understand these problems and also allows incorporating ones own intuition, intelligence and knowledge acquired from past experiences in solving them. It is felt that these uncertainties can be properly modeled with the help of fuzzy set theory and fuzzy reasoning. In the fuzzy planning of distribution systems, we can introduce the concept of risk (exposure) associated with the assessment of the possibility that the power flows in the feeders and DG units surpass their power capacity limits. At this point the concept of Pareto optimality can be introduced. A solution is said to be Pareto-optimal or "non inferior" if any objective can not be improved without degrading others.

The multi-objective possibilistic model determines the non-dominated solutions with using genetic algorithm to minimize the (fuzzy) economic cost and the risk (exposure), whereby the risk of surpassing the power capacity limits of the feeders and substations is minimized and, furthermore, the risk of surpassing the allowed voltage drop limits at the network nodes is also minimized.

Several approaches to solve the DG siting and sizing problem in distribution system have been proposed. In references [3, 4] DG siting and sizing problem are analyzed to improve reliability, power loss and voltage profile with considering deterministic demand on load points. In [5-10] DG siting and sizing problem in distribution network are analyzed to improve only power loss and voltage profile. Refs. [6, 11] were studied the effect of DG penetration in network on power loss reduction and voltage profile improvement in different load levels. In [13], DG siting and sizing problem is fulfilled to compromise multi-objective function consisting of energy not-supplied cost, improvement cost of network and energy loss cost. The aim in this paper is to model inherent uncertainty of demand on load points with using fuzzy set theory, then causing compromise between costs (arises from

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DG installation, repair and operation cost, and energy loss cost) and risk (exposure) related to the network to reach a realistic solution.

II. DG IMPACTS AND MODELING

DG offers a long list of benefits, which can be, primarily, classified into three broad categories, namely, economical, technical and environmental advantages. Economical advantages cover saving world fuel, saving transmission and distribution cost and reducing wholesale electricity price. On the other hand environmental advantages include low noise and low emission.

Technical advantages cover a wide variety of issues such as peak load saving, good voltage profile, reduced system losses, improved continuity and reliability, removal of some power quality problems and relaxed thermal constraints of Transmission and Distribution (T&D) feeders. Reducing the total system losses could be of interest to some utilities in the developing countries as some of them are losing 15-20% of their total generation as losses while this figure for a well-developed power system is well under 100/o. However, the placement and size of the DG are two crucial factors in loss reduction as will be shown in the paper.

A wide variety of DG technologies and types exists: renewable energy sources such as wind turbines and photovoltaic, micro-turbines, fuel cells, and storage energy devices such as batteries. The main reason of using DG units in power system is technical and economic benefits that have presented as follows [6, 7].

Some of the major technical benefits:

- reduced line losses;
- Voltage profile improvement;
- Reduced emissions of pollutants;
- Increased overall energy efficiency;
- Enhanced system reliability and security;
- Improved power quality;
- Relieved T&D congestion.

And some of the major economic benefits:

- Deferred investments for upgrades of facilities;
- Reduced O&M costs of some DG technologies;
- Reduced fuel costs due to increased overall efficiency;
- Reduced reserve requirements and the associated costs;
- Lower operating costs due to peak shaving;
- Increased security for critical loads.

Depend on contract type and generator control condition, DG units can be used as the PQ model (like a generator with constant active and reactive power close to load) or the PV model (for generate active power to fix the voltage on defined bus). In this paper siting and sizing of both model (PQ and PV) are considered.

III. FUZZY SET THEORY

In many practical applications fuzzy sets are applied in the form of fuzzy numbers. Input parameter's modeling is implemented with fuzzy set theory to use them in fuzzy load flow. The shape of this membership function [1] is determined by the expert persons that have enough information and experience about network characteristic. Fuzzy model gives a realistic sight about future demands of power distribution system because this model considers inherent uncertainty of future load points [2].

A. Fuzzy power flow

The power demand at each node can be represented using a value d_1 (the "most favorable" demand), a value d_3 (the "most unfavorable" demand), and a value d_2 (demand with the highest possibility of existence in the future that corresponds to the value 1 of the membership function μ. A fuzzy power demand represents simultaneously a large set of possible values of the power demand in the future, at a given node on the distribution network, describing the intrinsic uncertainty of such future demand. The fuzzy (possibilistic) variables are denoted by the symbol (~) in the possibilistic model. Fuzzy power flows (also represented by fuzzy triangular numbers) are transmitted by the lines of the distribution network to supply the fuzzy power demands of the nodes.

There are three well-known power flow solution techniques, which are Gauss-Seidel, Newton-Raphson (N-R) and the Fast decoupled methods. Among the three methods the N-R method was chosen for its accuracy and computational time. Such fuzzy power flows and the fuzzy voltages at nodes are calculated with Newton-Raphson power flow method that converted to the fuzzy power flow with applying the fuzzy numbers theory [1, 2]. The equations related to fuzzy active and reactive power injected to i^{th} bus can be expressed by (1):

$$\begin{aligned} \tilde{P}_i &= \tilde{V}_i \sum_j \tilde{Y}_{ij} \tilde{V}_j \cos(\tilde{\delta}_i - \tilde{\delta}_j - \tilde{\gamma}_{ij}) \\ \tilde{Q}_i &= \tilde{V}_i \sum_j \tilde{Y}_{ij} \tilde{V}_j \sin(\tilde{\delta}_i - \tilde{\delta}_j - \tilde{\gamma}_{ij}) \end{aligned} \tag{1}$$

Where,

$\tilde{Q}_i, \tilde{P}_i$: Fuzzy active and reactive injected power to i^{th} bus

$\tilde{\gamma}_{ij}, \tilde{Y}_{ij}$: Amplitude and phase of fuzzy admittance between bus i and j respectively.

$\tilde{\delta}_i, \tilde{V}_i$: Amplitude and phase of fuzzy voltage bus i respectively.

The Jacobian matrix will be calculated using equation (2). Therefore, the voltage and phase of different buses of system will be calculated with solving equations (1) and (2) repeatedly and finally, latter results will be saved with satisfying the convergence condition of load flow problem. Also, with substituting these results in equation (1), the quantity of fuzzy active and reactive power flow from slack bus can be calculated. It is worth mentioning here that, mathematic operations that has been used in equations (1) and (2), uses fuzzy number relations that represented in Ref. [1, 2].

$$\begin{bmatrix} \Delta \tilde{P}_{PV} \\ \Delta \tilde{P}_{PQ} \\ \Delta \tilde{Q}_{PQ} \end{bmatrix} = - \begin{bmatrix} \dfrac{\partial \tilde{P}_{PV}}{\partial \tilde{\theta}_{PV+PQ}} & \dfrac{\partial \tilde{P}_{PV}}{\partial \tilde{V}_{PQ}} \\ \dfrac{\partial \tilde{P}_{PQ}}{\partial \tilde{\theta}_{PV+PQ}} & \dfrac{\partial \tilde{P}_{PQ}}{\partial \tilde{V}_{PQ}} \\ \dfrac{\partial \tilde{Q}_{PQ}}{\partial \tilde{\theta}_{PV+PQ}} & \dfrac{\partial \tilde{Q}_{PQ}}{\partial \tilde{V}_{PQ}} \end{bmatrix} \begin{bmatrix} \Delta \tilde{\theta}_{PV+PQ} \\ \Delta \tilde{V}_{PQ} \end{bmatrix} \tag{2}$$

B. Comparison of Objective Function Values

As we have mentioned before, possibility distributions (triangular fuzzy numbers) are used to represent several magnitudes (i.e., demand, power flow, voltage, etc.). The nonlinear objective function associated with the economic cost corresponds to fuzzy values. These fuzzy values must be compared and ranked to assess several planning solutions. The ranking function "removal" [14] allows determining and comparing these values. For example, in Fig. 1, the removal of the fuzzy value $\tilde{a}$ for an $\alpha\_cut = h_1$ is defined as $R_{h_1} = \left(a_{h_1}^{l} + 2a_2 + a_{h_1}^{u}\right)/4$.

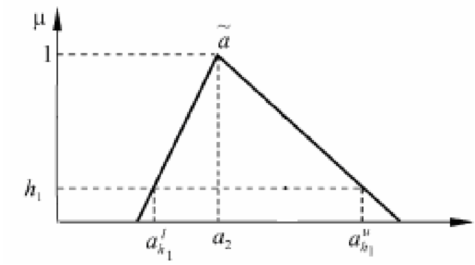

Fig. 1. Fuzzy variable

C. The related risk with system

A classical technical constraint of feeder (or substations) power capacity limit in optimal power distribution planning is usually met for a given "degree of possibility" from the standpoint of fuzzy power flows (or voltage drop constrains from the standpoint of fuzzy voltages). Thus, above a given degree of possibility, there is a risk that the power capacity limit constraint of a feeder (or substation) will not be met; this is known as "exposure" [14, 15] (similar ideas can be presented for exposure referring to fuzzy voltages).

Thus, the exposure EX_{IIK} associated with the power flow of the k-th feeder is the lowest $\alpha 1-$level at which the fuzzy power flow $\tilde{x}^k$ of the feeder is "lower" than (or "equal" to) the power capacity limit $\tilde{x}^k{}_{\max}$ of the feeder (See Ref. [1] for more details). Then,

$$EX_{ILK} = \min\{\alpha_1 \mid \tilde{x}^k \leq_{\alpha_1} \tilde{x}^k{}_{\max}\} \tag{3}$$

The exposure EX_{ISK} associated with the power flow in the k[th] substation is the lowest $\alpha 2-$level at which the fuzzy power flow $\tilde{x}^k$ in the substation is "lower" than (or "equal" to) the power capacity limit $\tilde{x}^k{}_{\max}$ of the substation. Then,

$$EX_{ISK} = \min\{\alpha_2 \mid \tilde{x}^k \leq_{\alpha_2} x^k_{\max}\} \tag{4}$$

The exposure EX_{VDK} associated with the voltage of the *k-th* node is the lowest $\alpha 3-$level at which the fuzzy voltage $\tilde{V}^k$ of the node is "higher" than (or "equal" to) the allowable lowest voltage limit $(V_{\min,k})$. Then,

$$EX_{VDK} = \min\{\alpha_2 \mid V_{\min,k} \leq_{\alpha_2} \tilde{V}_k\} \tag{5}$$

The exposure EX_{Il-RED} of a considered distribution feeder's network (composed by the set of N_{Fe} feeders) is

$$EX_{IL-RED} = \max\{EX_{ILK} \mid k \in N_{Fe}\} \tag{6}$$

Similar concepts can be established for exposure EX_{IS-RED} for substations and EX_{VD-RED} for voltages of a considered power distribution network. Thus,

$$EX_{IS-RED} = \max\{EX_{ISK} \mid k \in N_{Se}\} \tag{7}$$

$$EX_{VD-RED} = \max\{EX_{VDK} \mid k \in N_{Ne}\} \tag{8}$$

Where, N_{Se} and N_{Ne} are, respectively, the sets of substations and nodes of the distribution network (the one that is being evaluated).

Then, the exposure EX of the considered network is

$$EX = \max\{EX_{IL-RED}, EX_{VD-RED}, EX_{IS-RED}\} \tag{9}$$

IV. DG SITING AND SIZING

Great attention should be rendered to the problem of allocation and sizing of DG. The installation of DG units at non-optimal places can result in an increase in system losses, implying in an increase in costs and, therefore, having an effect opposite to the desired. For this reason, the development of an optimization methodology capable of indicating the DG unit allocation and sizing that improves the system operation characteristics can be very useful for the system planning engineer when dealing with the increase of DG penetration that is happening nowadays. In this paper Genetic Algorithm (GA) has been used as an optimization tool.

The optimization process is solved by the combination of GA techniques with power flow analysis to evaluate DG impacts in system losses and voltage profile. The power loss and voltage profile evaluation is fulfilled by fuzzy power flow method for radial networks with considering dispersed generators.

A. Genetic algorithm

GA is one of the stochastic search algorithms based on the mechanics of natural genetics. A solution variable for the problem is first represented using artificial chromosomes (strings). In other words, the problem is encoded to strings that GA can handle. A string represents one search point in the solution space. GA is a parallel search method because it uses a set (population) of strings (i.e. multiple search points). It modifies strings (searching points) using natural selection and genetic operators such as cross-over and mutation. After convergence, strings are decoded to the original solution variables and the final solutions are obtained. The GA is a search technique originally inspired by biological genetics. Unlike various constructive optimization procedures which use sophisticated methods to obtain a good single solution, it deals with a set of solutions and tends to manipulate each one in the simplest way. It requires the solutions to be presented or coded as a finite-length string.

B. *Coding and decoding*

In the encoding process of the siting and sizing problem of DG units, decimal numbers are used for encoding of chromosomes instead of binary numbers. In the encoding procedure each gene stand for a system nodes therefore, the length of each chromosome is equal to number system buses. Each gene could be selected between 0-N_{DG} that, N_{DG} is the total number of DG units with standard capacities which are considered in system planning period. In the appendix section, Fig. 2, shows an example to explain this procedure. For example; on first bus, there is no DG unit and on second bus, the DG unit of forth type and on third bus, the DG unit of first type and so will be installed.

V. MULTI-OBJECTIVE PROBLEM ANALYSIS

A planning method is proposed to optimize two objective functions: fuzzy economical cost and EX. This method generates a set of Pareto-optimal solutions using genetic algorithm in each stage. This method transforms one objective into constraints, by specifying bounds to them, and the remaining objective, which can be chosen arbitrarily, is the objective function to optimize. In other words, the multi-objective problem is transformed into a single-objective optimization problem, which is resolved by classical single-objective algorithms [13-14]. As a result, a wide set of optimal solutions (Pareto set) may be found. Thus, an engineer may have a whole set of optimal alternatives before deciding which solution is the best compromise of different features. The bound is the parameter that has to be varied in order to find multiple solutions. In the following sections, the main components of the method are described.

A. *Search of the set of non-dominated solutions*

Each planning solution k obtained with the multi-objective possibilistic model has an associated fuzzy value for the objective function of fuzzy planning cost $\tilde{C}_k(y,\tilde{x}) = \tilde{C}_k$ and a deterministic value for the exposure EX_k. The exposure can range from 0 to 1. Thus, a partition of the space of planning solutions is carried out by limiting the values of one objective function using mathematical constraint that lead systematically to successive planning solutions. Let us consider the mathematical constraints:

$$EX \le EX_{meta} \tag{10}$$

Where, $EX_{meta} \in [0,1]$

Then, the following optimization is successively solved each time, by varying systematically the value of EX_{meta}

$$\begin{aligned} &Min \quad \tilde{C}(y,\tilde{x}) \\ &s.to. \\ &EX \le EX_{meta} \\ &(y,\tilde{x}) \in X_f = \{(y,\tilde{x}) \mid g_r(y,\tilde{x}) \{\tilde{\le},\tilde{=},\tilde{\ge}\} 0, r \in R_f\} \end{aligned} \tag{11}$$

Similarly, our multi-objective fuzzy model uses integer variables (y) and fuzzy continuous variables $\tilde{x}$ in the multi-objective optimization of fuzzy planning cost $\tilde{C}(y,\tilde{x})$, and exposure EX, subject to the fuzzy technical constraints $g_r(y,\tilde{x}) \{\tilde{\le},\tilde{=},\tilde{\ge}\} 0$.

$$\begin{aligned} &\tilde{C}(y,\tilde{x}) = \sum_{i=1}^{\mathrm{Nnode}} (\tilde{cf}_i)_\Omega (y_i) + \\ &\sum_{i=1}^{N} (C_E \times T \times \mathrm{LSF_i} + C_P) \times \mathrm{PW}^i \times \tilde{\mathrm{P}}_{\mathrm{loss,i}} \\ &\mathrm{PW} = \left(\frac{1+\inf r}{1+\mathrm{intr}} \right) \end{aligned} \tag{12}$$

Where,

N= period of planning (years);

$(\tilde{cf}_i)_\Omega$ = fuzzy fixed cost of a DG unit of size Ω to be installed on i[th] bus;

$\tilde{\mathrm{P}}_{\mathrm{loss,i}}$ = fuzzy power loss of network in i[th] year;

T = 8760 hrs in the year

C_P = Levelized annual demand cost of losses (R/kW-year)

C_E = Energy cost of losses (R/kWh);

PW^i = present worth coefficient for i[th] year;

$\mathrm{LSF_i}$ = loss factor in i[th] year;

$(y_i)_\Omega$ = 1, if a DG unit of size Ω associated with i[th] bus is installed. Otherwise, it is equal to 0;

infr, intr are inflation rate and interest rate respectively.

In (8), notice that the fuzzy mathematical operations are algebraic operations with fuzzy numbers.

B. *Constraints*

The safe operation of power system equipment and quality of supply requires voltages to be maintained close to nominal:

$$V_i^{\min} \le V_i \le V_i^{\max} \qquad \text{i=1… N} \tag{13}$$

$$P_{ij}^{\min} \le P_{ij} \le P_{ij}^{\max} \qquad \text{i=1… N} \tag{14}$$

Where, $V_i^{\min}$ and $V_i^{\max}$ are the lower and upper bounds of the bus voltage.

As DG capacity is inherently limited by the energy resource at any given location it is necessary to constrain capacity between maximum and minimum levels:

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \qquad \text{i=1… } N_{dg} \tag{15}$$

N_{dg} is the number of installed DG in the system.

Constraint about reactive power of DG:

$$\begin{aligned} &Q_{gi} = Q_g \quad \text{if} \quad Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \\ &Q_{gi} = Q_{gi}^{\min} \quad \text{if} \quad Q_{gi} \le Q_{gi}^{\min} \qquad i=1\ldots N_{dg} \\ &Q_{gi} = Q_{gi}^{\max} \quad \text{if} \quad Q_{gi}^{\max} \le Q_{gi} \end{aligned} \tag{16}$$

Now the problem can be stated as minimization of the objective function (F) satisfying all system constraints stated above.

A significant amount of research effort is being expended on active management of distribution networks wherein reactive power and voltage will be controlled to enhance DG penetration.

The planning solutions obtained with this method are compared among themselves to determine a set of non-dominated solutions.

Our model considers two kinds of costs: fixed and variable cost. The fixed cost comprises building and equipment costs and variable cost includes the cost of energy losses.

The third term of equation (16) represents other constraints of DG siting and sizing problem that consists of: 1- the algebraic sum of injected power from main supply and DG units must be equal to demand and power loss in the network. 2- The generated power of DG units must be equal or smaller than its nominal capacity [16].

The optimization process of equation (16) will be realized with varying amount of EX_{meta} and genetic algorithm implementation to deem it necessary.

C. Selection of the best multi-objective planning solution

After analyzing the set of non-dominated solutions, the planner can select the final non-dominated solution, considering the most satisfactory values of the three objectives and according to his/her experience and professional point of view. In this paper, a max-min approach is used to select the best (final) multi-objective planning solution. Each solution in the set of non-dominated solutions has an associated vector of values $(\tilde{C}_k, EX_k)$ that can be normalized using the following expression:

$$\left(\frac{C_{\max} - R(\tilde{C}_k)}{C_{\max} - C_{\min}}, \frac{EX_{\max} - EX_k}{EX_{\max} - EX_{\min}} \right) \tag{17}$$

Where, $C_{\max}$ and $EX_{\max}$ are the “removal” values of the maximum values obtained for the objective function of fuzzy economic cost and for the exposure function, respectively, and $C_{\min}$ and $EX_{\min}$ are the “removal” values of the minimum values obtained. Note that the result of this normalization gives the vector (1, 1) for the ideal point $(C_{\min}, EX_{\min})$ and the vector (0, 0) for the anti-ideal point $(C_{\max}, EX_{\max})$, that is, it represents the level of satisfaction for each objective function. Afterwards, a max-min approach, shown in (102), is applied to select the best (final) multi-objective planning solution (that is, the most satisfactory solution using the aforementioned approach).

$$\max\left\{ \min_k \left[\left(\frac{C_{\max} - R(\tilde{C}_k)}{C_{\max} - C_{\min}}, \frac{EX_{\max} - EX_k}{EX_{\max} - EX_{\min}} \right) \right] \right\} \tag{18}$$

VI. Test Results

A study case of 33-bus system shown in Fig. 2, Ref. [16] is considered. Load demand and lines information of system is given in this reference. The Table of technical and economic information associated with distribution system and DG units are given in Tables 1 and 2, respectively, where the costs are hypothetical. The period taken into consideration for the planning study is 10 years long, with all nodes existing at the beginning of the period. For each node, a constant power demand growth rate of 5% per year has been assumed. The optimization algorithm may use different sizes of DG generators to be chosen within a discrete number of prefixed sizes; in the proposed example, 50-100-150 kW generators have been adopted.

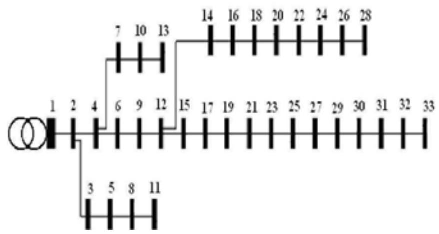

Fig. 2- 33 bus power distribution system Ref. [16]

TABLE I

TECHNICAL AND ECONOMIC INFORMATION OF NETWORK

N	10	V-nominal	12.66kv
Intr	15%	CE	50
Infr	15%	Min-Voltage	0.9pu
Lsf	0.35	Load growth	5%

TABLE II

TECHNICAL AND ECONOMIC INFORMATION OF DG UNITS

Number	DG type	P(KW)	Q(KVAR)	Cost of DG unit
1	PV	60	-	37500000
2	PV	75	-	42613636
3	PV	100	-	51652892
4	PV	125	-	58696468
5	PQ	60	50	30000000
6	PQ	75	60	34090909
7	PQ	100	85	41322314
8	PQ	150	130	56348610

The Fig. 3 shows the produced non-dominated solutions of considered problem (EX vs. Removal of cost). According to the Fig. 1, decreasing the planning cost will cause to increase related exposure that shows the concept of non-dominated solutions.

The best selected solution with using max-min procedure is given in Table 3.

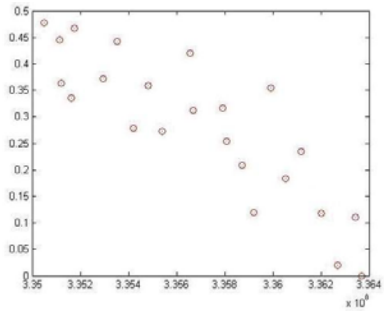

Fig. 3. Non-dominated solutions of possibilistic planning model of network

TABLE III
THE BEST SELECTED SOLUTION WITH MAX-MIN PROCEDURE LOAD

Bus	Type of selected DG unit
28	DG type 5
29	DG type 8
33	DG type 7

In many of the cases the optimal locations appear to be towards the end of the feeders or close to branch points. According to Table 3, it can be seen that the best place for DG installation selected on the end of feeders that Ref. [9] is confirmatory to this point.

The global cost during the given study period without DG is equal to 16567.6 k€ (2227.9 k€ are network costs, and 14339.7 k€ is the cost of energy delivered by the transmission network). This high network cost is mainly due to the enforcement of a large number of branches and to the high value of energy losses: both costs can be reduced resorting to EG as demonstrate in the following. It must be noted that the DG penetration level rises from the initial 16.36% up to the 34.54% as reported in Table 4.

If the deterministic demand is placed in load points of planned network, since the system in planned for wide range of load information, the operation constraints of problem will not be violated.

TABLE IV
COMPARISON BEFORE AND AFTER DG PLACEMENT CONDITIONS

	Without DG	With DG
EX	0.645	0
Min voltage (PU)	33^{th} bus: [0.89313, 0.90378, 0.91421]	33^{th} bus: [0.92537, 0.93543, 0.94529]
Power loss Removal (KW)	210.99	150.33
Cost Function Removal ($R)	3.5449e+008	2.5257e+008

VII. CONCLUSION

This article represents a possibilistic (fuzzy) model for optimal DG siting and sizing to solve a multi-objective problem: fuzzy cost function and Exposure (maximization of robustness) that obtains non-dominated solutions. Possibilistic model contrary to deterministic model (that considers a single value for demand of load points), considers wide range of demand amounts for future load points and can model inherent uncertainty of network with high reality. This method can be determined operation-mode (PV or PQ) of DG. Because of considering load uncertainty, it can be obtained realistic results. The numerical example confirms the validity of the proposed method.

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