Fuzzy based DG allocation for Loss Minimization in a Radial Distribution System

A. Metia and S. Ghosh

Abstract—**Due to the restructuring in electricity market and environmental concerns penetration level of DG unit has been increased rapidly. It is also playing a significant role in minimization of line losses of a power system network. So it is very important to define the size and location of distributed generation unit to be allocated in a power system network. On the other hand due to radial distribution systems basic inherent features such as radial structure, a wide range of X/R ratios, and a large number of nodes; the optimal sizing and siting problem of a DG unit cannot be determined by the conventional techniques, which are used for transmission systems. A novel method for the estimation as well as minimization of losses in a radial distribution system with DG unit has been presented in this paper. It also improves the voltage profile of the existing power systems and in addition a combined and optimal power factor is also calculated. An algorithm is presented in this paper to obtain the optimum position of DG units in the distribution network based on the available amount of DG using Fuzzy logic. Forward backward sweep method makes the load flow solution faster. Test results on a 33-bus system reveal that the superiority and simplicity of the proposed algorithm.**

Keywords— **Fuzzy logic, distributed Generation, loss reduction, optimal location, optimal size.**

I. INTRODUCTION

THE penetration level of distributed generators is increased due to the restructuring in electric power system. Distributed generators which are used for local power generation in a distribution system are generally connected to the load end directly. These DGs are normally ranged from few kW to few MW and they are not centrally placed. Most of the distribution systems are conventionally planned as passive network and they are capable of unidirectional power flow. However, distribution networks are transferred to active network with bidirectional power flow by installing a DG unit in the distribution system. In spite of the restructuring of electricity market, utilization of DG unit in the distribution system can make many benefits such as voltage profile improvement, real and reactive power loss reduction, environmental concerns, power quality improvement, investment risk reduction, reliability and security improvements [1, 2].

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Power loss is varied from one country to another country which can be found from different statistics and studies. Different studies and statistics showed that distribution losses are 70% of the total power losses of the system [3] and 20% of total generated power is transferred into losses in a network [4, 5], and it would make a cost millions of dollar every year.So power loss reduction is one of the important solutions to improve the overall efficiency of a distribution system. To reduce the distribution system losses there are three well known techniques are available; network reconfiguration, optimal capacitor allocation and DG placement. Out of these three techniques DG allocation has both technical as well as economic benefits that have presented in the research paper [7-10].

Recently many studies have been employed to reduce the system losses by optimal sizing and siting of DG. Most of the methods are analytical and some of them are heuristic and metaheuristic methods. In the research paper [11] a reduced gradient approach has been presented to obtain the appropriate size of DG unit. An analytical method based on $2/3$ rule as a rule of thumb has been presented in this research paper to obtain optimal placement and optimal size of DG unit [12]. Many analytical approaches [4-8] were utilized for the DG allocation and sizing. Two analytical methods for a fixed size DG allocation are introduced in the research paper [4] out of which first one is applicable for radial system whereas second one is applicable for meshed network. Exact loss formula based analytical method is presented in [18] whereas analytical expressions for multi DG units are developed in the research paper [14]. A loss sensitivity factor based analytical method has been proposed to obtain the optimal size and position of a single DG unit in a distribution system [15]. A probabilistic approach has been developed in [19] for the selection of distributed generator location an hourly load or daily load changes are weighted according to the load magnitude and the location points are also weighted according to their load magnitude. The application of the proposed method demonstrated the efficiency of the method to solve the problem of DG sizing and siting. In [20] a MTLBO algorithm has presented to determine optimal size and optimal location of distributed generators in a distribution system. The optimal positioning and sizing problem was considered as MINLP problem in this paper. Authors in [21] has presented simultaneous allocation of distributed generators and capacitors for reducing active as well as reactive power loss minimization in a radial distribution network using a memetic algorithm which is the combination of local search and genetic algorithm. A PSO algorithm with constriction factor has been used in [22] to determine the optimal sizes and location of multiple DG units. A predetermined load growth with voltage regulation for five year was considered as constraints in this research paper. The results proved that multiple DG units which are allocated in distribution system can reduce both real and reactive power loss, purchase cost of energy, voltage deviation in the distribution system. A BSOA algorithm has been adopted to assign distributed generator units in a radial distribution network in [23], where the weighting factor is adopted with objective function to minimize real power loss and also to improve the voltage profile. The numerical results described that the proposed method is more effective and efficient in comparisons with the analytical and other heuristics methods.

In this paper a backward forward sweep methodology has been used for estimation of losses in a radial distribution system. After the estimation of losses a fuzzy expert system is implemented to standard test system to find the suitable node where the DG unit is to be placed such that the system losses is minimized as well as voltage profile of the system is improved. After getting the suitable node an analytical methodology has been used to compute optimum size of DG unit. It is considered that the DG unit is located in the primary of the distribution system to reduce the losses. The developed methodology is effective and suitable for allocating a single DG unit in the radial system.

The rest of the research paper is developed as follow: section II includes location and sizing problem of DG units. Section III contains modeling and problem formulation. Section IV contains Backward/forward sweep method for load flow and section V includes proposed fuzzy expert system to find optimal location, the analytical approach to obtain optimal size of DG unit is described in the section VI. Optimal results are presented and summarized in section VII. At final section VIII conclusions and remarks are described.

II. ALLOCATION AND SIZING PROBLEM

The optimal allocation and sizing of a DG unit is one of the important factors for loss reduction in a distribution system. *Fig. 1* shows a three dimensional plot between power losses and DG size at each buses in a distribution system. Figure 1 shows that as the DG size is increased for a particular bus the losses of a distribution network are reduced. However the loss is increased if the DG size is increased beyond the optimal DG size at that particular location. So whenever the DG size is increased more than the optimal value, the loss is increased and it may go beyond the loss of the base case loss. It is also important that minimization of losses are directly depends on location of DG.

From the *Fig. 1* it can be concluded that for a particular distribution system it is irrelevant to construct very high capacity DG unit. Allocation of a high capacity DG unit will cause very high system losses. So the size selection process of DG unit is carried out based on the size of distribution system (based on load in MW). The reason for the relation between higher DG unit capacity with higher losses can be explained that the distribution system is designed in such a way that such the power flows initially from sending end to the receiving end.

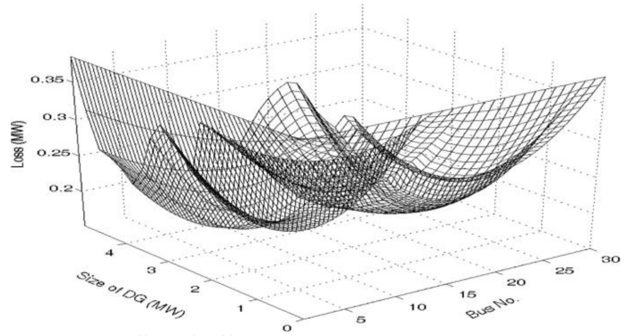

Fig.1. Effect of different DG size and their location on losses [18]

The conductor sizes are generally reduced from sending end towards the receiving end. So without change of network any installation of a large size DG unit will make excessive power flow in small size conductors and as a result it causes higher losses.

The DG placement problem is solved by location issue first then followed by the sizing issue

III. MODELING AND PROBLEM FORMULATION

3.1 Different Load model

In power system loads are modeled into three categories based on the static characteristics of the load. These are as follows.

- *Constant power*: In this load model active power and reactive power are independent of the voltage changes.
- *Constant current:* In this load model bus voltage is directly proportional with the active and reactive power respectively.
- *Constant impedance*: In this load model active power and reactive power are directly proportional to the square of the bus voltage.

In this paper the loads are modeled as constant power model to study the behavior of loads.

3.2 DG model and their types

Based upon different point of view such as; type of connection, types, different operation mode DG unit can be modeled as PV bus or DG unit can also be modeled as PQ bus [24]. A DG unit which is already modeled as PQ bus can also modeled into three other types such as: DG unit has constant P and Q [25], DG unit having a certain specified value of P and power factor (PF) [25]. As a varying Q generator DG unit can also be modeled [25]. A DG unit having specified real power and bus voltage magnitude is modeled as PV bus DG unit [25]. DG units are many times modeled as PV node without considering dummy branch; they can inject reactive power to the distribution system and support the voltage profile [26].

DGs with smaller capacity and in the form of constant PQ model are very much sufficient for the loss minimization of a radial distribution system. DG unit as negative load is assumed in this presented research paper.

Various types of DG technologies used in a distribution system are presented in TABLE I.

TABLE I
DIFFERENT DG TECHNOLOGIES

Types of DG	Real power (P)	Reactive power (Q)	Example
1	+	0	PV arrays, Battery, fuel cells
2	0	+	Capacitor
3	+	+	Diesel engine based Synchronous generators
4	+	-	Induction generators
(+) Produces		(-) Absorbs	

IV. OBJECTIVE FUNCTION AND BACKWARD/FORWARD SWEEP POWER FLOW METHOD

4.1 Objective function

'Exact loss' formula [30] can be used for the estimation of total real power losses of a radial distribution system by equation (1).

$$\text{Min } P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j - P_iQ_j)] \quad (1)$$

Where $\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j)$, $\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_j)$

and $r_{ij} + jx_{ij} = z_{ij}$; is the impedance of *ij* th matrix.

4.2 Backward/ Forward sweep power flow method

Three phase distribution system is balanced considering this a load-flow solution is carried out, so the three phase system can be represented as a single line diagram. A direct load flow can be used for the radial distribution system [27]. Now considering branch-1 the receiving end node voltage can be calculated as

$$V(2) = V(1) - I(1)Z(1) \quad (2)$$

Similarly for branch 2

$$V(3) = V(2) - I(2)Z(2) \quad (3)$$

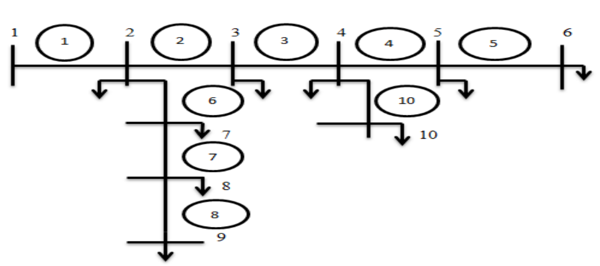

Fig.2. A simple radial distribution system

So as the source node voltage $V(1)$ is already known so if we can determine the branch current $I(1)$ then it will be very easy to compute $V(2)$ from Eq. (2). So in the same way by computing the branch current $I(2)$ we can easily determine the node voltage $V(3)$. Similarly we can determine the node voltages of node 1, 2 …N_{no}(no. of nodes) in forward sweep.

So based on the above equation the voltage of node 'i' can be written as

$$V(i) = V(i-1) - I(i)Z(i) \quad (4)$$

The load current of node 'i'; $I_L(i)$ can be calculated as:

$$I_L(i) = \frac{P_L(i) - Q_L(i)}{V(i)^*}; \qquad \text{for i= 1,2……..} N_{no} \quad (5)$$

Where $P_L(i)$ = active power of load connected to node 'i'

$Q_L(i)$ = reactive power of load connected to node 'i'

Branch current through node '*i*' i.e. $I(i)$ is the sum of load current $I_L(i)$ of node 'i', and the branch currents which are connected to this line can be represented as

$$I(i) = I_L(i) + \sum_{j\in\gamma_i} I(j) \quad (6)$$

Where γ_i is consisting of all the branches connected to node 'i' and γ_i is zero for all terminal node.

So the current $I(i)$ connected to end node 'i' can be expressed as

$$\mathrm{I(i)} = \mathrm{I_L}(i) \quad (7)$$

So equation (6) and (7) are utilized in backward sweeps from all end nodes towards the root node for calculation of current.

4.2.1 Calculation of real and reactive power losses

The real and reactive power loss of a distribution system can be expressed as given below

$$P_L(i) = |I(i)|^2R(i) \quad (8)$$
$$Q_L(i) = |I(i)|^2X(i) \quad (9)$$

V. OPTIMAL NODE DETERMINATION USING FUZZY EXPERT SYSTEM (FES)

For a given single source radial distribution system it is not possible to reduce the losses which are associated with real and reactive component of the branch currents because all these real and reactive power is supplied by the single source at the source node. This limitation can be overcome by placing DG units at different nodes of the system for loss reduction. So the real and reactive powers are generated locally by installed DG unit. The location of DG is chosen based on fuzzy expert system. The location must be one that gives minimum losses along with the best voltage profile.

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5.1 FES implementation

The fuzzy expert system (FES) consists of a set of rules. These rules are developed in a standard way. Different rules are designed and defined to determine the suitable node at which DG could be placed in fuzzification process. In the fuzzification process, the power loss factor (PLF) and voltage index (VI) are converted into fuzzy. Linguistic terms for power loss factor (PLF) is described by very low (VL), low (L), medium low (ML), medium high (MH), high (H), very high (VH) and linguistic terms for voltage index is described as low (L), medium low (ML), medium (M), medium high (MH), high (H). Different membership functions are generated to represent all these linguistic terms. Trapezoidal type membership functions are used in the following fuzzy expert system and they are shown in the Fig. 3 and Fig. 4 respectively.
The power loss factor (PLF) and the voltage index (VI) are the two inputs to the fuzzy (FIS), which determines the optimal position for allocation of DG by fuzzy inferencing. The inference involves heuristic rules for the determination of output decisions. In this fuzzy inference system there are two input variables (PLF, VI) and (7, 5) fuzzified variables respectively so that the fuzzy inference system has a set of 35 rules.

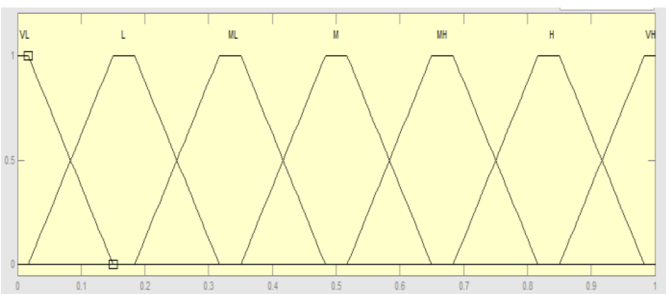

Fig.3. Power loss factor membership functions.

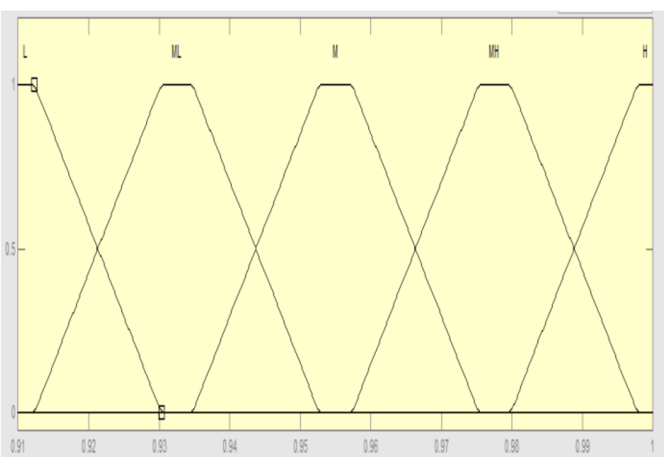

Fig.4. Voltage index membership functions

The DG unit is allocated in a radial distribution system in such a way that power loss factor should be maximum and the voltage index should be minimum. These two objectives are more important while designing the heuristic rules for fuzzy inference system (FIS). All these rules are expressed as the following way:

IF premise (antecedent).THEN conclusion (consequent).
To determine the DG suitability at a node a set of fuzzy rules have been employed. The rule base for optimal DG placement is presented in the fuzzy decision matrix shown in Table 2 and illustrated in *Fig. 6*. The output of fuzzy inference system is DG placement suitability index and it is also described by the linguistic terms very low (VL), low (L), medium low (ML), medium (M), medium high (MH), very high (VH). These linguistic terms are also represented by membership functions and it is shown graphically in Fig.5.

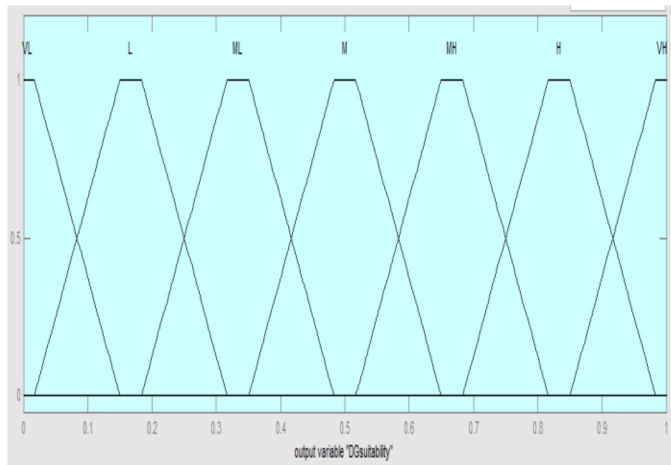

Fig.5. DG placement suitability index membership functions

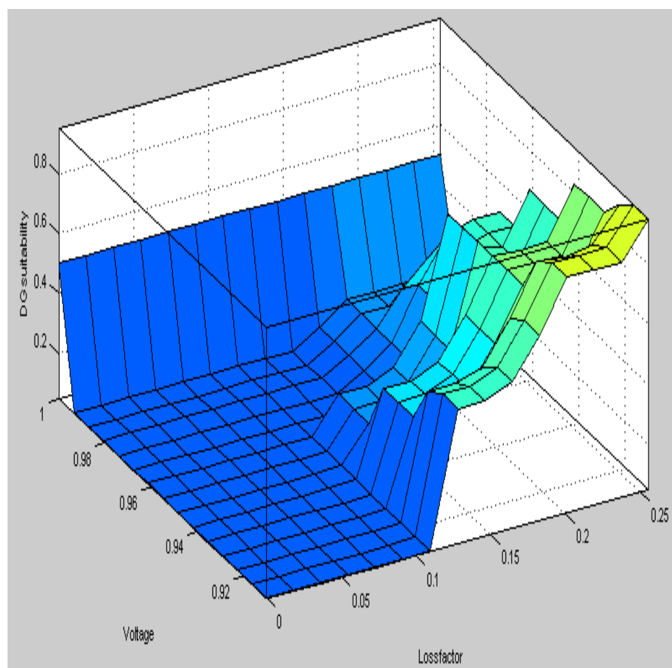

Fig.6. Fuzzy rules in graphical representation

TABLE II
FUZZY DECISION MATRIX

AND	Voltage index (VI)					
		Low (L)	Medium Low (ML)	Medium (M)	Medium High (MH)	High (H)
Power loss factor (PLF)	Very Low (VL)	VL	VL	VL	VL	VL
	Low (L)	VL	VL	VL	VL	VL
	Medium Low (ML)	M	ML	L	VL	VL
	Medium (M)	MH	M	ML	L	L
	Medium High (MH)	H	MH	MH	ML	L
	High (H)	H	MH	M	M	ML
	Very High (VH)	VH	H	MH	M	L

5.2 Fuzzy inference and defuzzification technique

Several rules are implemented with some degree of membership after the inputs are given to the fuzzy expert system (FES) which is obtained from the load-flow program i.e. power loss factor and voltage index. In this fuzzy expert system method Mamdani's maximum-minimum method of inference has been used. Regarding the DG placement problem, the DG suitability membership function, μ_s of node i for k fired rules are given by the equation (10)

$$\mu_s(i) = \max[\min[\mu_p(i), \mu_v(i)] \quad (10)$$

The two membership functions of power loss factor and voltage index are represented by μ_p and μ_v respectively.
After the calculation of DG suitability membership function for a particular node it must be defuzzified to a scalar value. This defuzzification method helps to determine the ranking of different node's suitability. To defuzzify the fuzzified values a centroid method has been used. DG suitability index can be determined as,

$$S = \frac{\int \mu_s(z).zdz}{\int \mu_s(z)dz} \quad (11)$$

VI. OPTIMAL DG SIZING BY ANALYTICAL METHOD

We are considering $a = (sign)\tan(\cos^{-1} PF_{dg})$ [17] for optimal positioning of a DG unit in a radial distribution system. The reactive power generated by a DG unit can be expressed by the following equation as:

$$Q_{\boldsymbol{dgi}} = aP_{dgi} \quad (12)$$

In which

$sign = +1$: reactive power supplied by a DG.
$sign = -1$: reactive power absorbed by a DG.
PF_{dg} = Power factor of DG

The active power and reactive power injected at bus i by a DG can be given by the following equation (13) and (14).

$$P_i = P_{dgi} - P_{di} \quad (13)$$
$$Q_i = Q_{dgi} - Q_{di} = aP_{dgi} - Q_{di} \quad (14)$$

From equation (1), (13), (14) the active power loss which occurred in the distribution system can be computed in the following way

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}[(P_{dgi} - P_{di})P_j + (aP_{dgi} - Q_{di})Q_j] + \beta_{ij}[(aP_{dgi} - Q_{di})P_j - (P_{dgi} - P_{di})Q_j]] \quad (15)$$

The partial derivative of Eq. (15) with respect to the active power injection from DG at bus 'i' becomes zero to obtain reduced active power loss.

$$\frac{\partial P_L}{\partial P_{dgi}} = 2\sum_{j=1}^{N}[\alpha_{ij}(P_j + aQ_j) + \beta_{ij}(aP_j - Q_j)] = 0 \quad (16)$$

Equation (16) can be written in the following way:

$$\alpha_{ii}(P_i + aQ_i) + \beta_{ii}(aP_i - Q_i) \sum_{\substack{j=1\\ j\neq i}}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) + a\sum_{\substack{j=1\\ j\neq i}}^{N}(\alpha_{ij}Q_j + \beta_{ij}P_j) = 0 \quad (17)$$

Now Let $X_i = \sum_{\substack{j=1\\ j\neq i}}^{N}(\alpha_{ij} P_j - \beta_{ij}Q_j)$

And $Y_i = \sum_{\substack{j=1\\ j\neq i}}^{N}(\alpha_{ij}Q_j + \beta_{ij}P_j)$ (18)

From the equation (13), (14), (17) and (18) we can obtain the equation (19) state as below

$$\alpha_{ii}(P_{dgi} - P_{di} + a^2P_{dgi} - aQ_{di}) + \beta_{ii}(Q_{di} - aP_{di}) + X_i + aY_i = 0 \quad (19)$$

Rearranging the above equation we can obtain equation (20) to get the formulae to compute the best size of a DG to be placed in distribution system to reduce losses

$$P_{dgi} = \frac{\alpha_{ii}(P_{di}+aQ_{di})+\beta_{ii}(aP_{di}-Q_{di})-X_i-aY_i}{a^2\alpha_{ii}+\alpha_{ii}} \quad (20)$$

The power factor of a DG unit is very important to minimize the total system losses and it also depends upon the DG type and its operating condition. When the power factor of a DG unit is specified then its size can be determined in the following way:

Type 1 DG: This kind of DG is injecting only active power such as fuel cells, photovoltaic system, micro-turbines. Power factor is unity for this type i.e. $PF_{dg} = 1$, $a = 0$. By reducing the equation (21) we can get the size of Type 1 DG.

$$P_{dgi} = P_{di} - \frac{1}{\alpha_{ii}}\left[\beta_{ii}P_{di} + \sum_{\substack{j=1 \\ j\neq i}}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j)\right] \quad (21)$$

Type 3 DG: This kind of DG is generating active power as well as reactive power such as diesel generators. Power factor is in the range $0 < PF_{dg} < 1, sign = +1$ and a is a constant. The best size of Type 3 DG for minimum loss can be obtained from the equation (14) and (20).

6.1 Optimal power factor

Let a distribution system having two buses, a source, a load. The DG unit is connected at load end as shown in Fig.6.

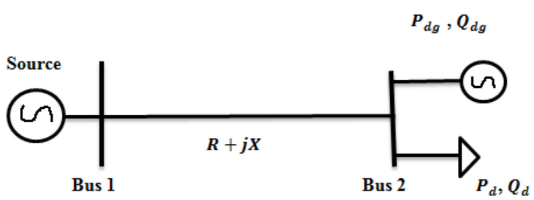

Fig.6. Distribution system with single DG unit.

PF of the single DG (PF_{dg}) connected to the distribution system can be obtained as,

$$PF_{dg} = \frac{P_{dg}}{\sqrt{{P_{dg}}^2 + {Q_{dg}}^2}} \quad (21)$$

PF of a single load (PF_d) can be obtained as,

$$PF_d = \frac{P_d}{\sqrt{{P_d}^2 + {Q_d}^2}} \quad (22)$$

When the PF of a single DG is equal to PF of combined load at that time the total load PF can be computed by Eq. (22) at that calculation the total active and reactive power can be obtained as,

$$P_d = \sum_{i=1}^{N} P_{di} \quad (23)$$

$$Q_d = \sum_{i=1}^{N} Q_{di} \quad (24)$$

It is found that minimum loss will be obtained if the power factor of DG (PF_{dg}) is equal to power factor of total load (PF_d). This can be expressed by equation (25)

$$PF_{dg} = PF_d \quad (25)$$

6.2 Computational procedure for the approach

The procedure to allocate a DG unit for loss minimization in a radial distribution system represented as below:

Step 1) Run the forward/ backward sweep load-flow for base case and find each branch as well as total losses and node voltages for the specified test system.

Step 2) Find the optimal node to allocate a DG unit.

(a) Develop the two input membership functions based on branch losses and node voltages and one output membership function of DG suitability index.
(b) Develop fuzzy rules (5×7) using Mamdani's method and defuzzify that to get optimal node for DG placement.
Step 3) Find the optimal power factor using equation (25).

Step 4) Obtain the optimal size of DG and compute the losses using the following steps:

(a) Allocate the DG unit at the appropriate position obtained from step 2, and vary the DG sizes in a very small steps using equation (14), (20), (21), by updating the values of 'α' and 'β' and finally compute the total real power losses by using the steps given below
(b) Select and store the DG size which gives minimum losses and discard other results.

Step 5) Update load data which is obtained in step 3, after allocating the DG unit with optimal size.

Step 6) Stop the procedure if the following occurs:

(a) If the voltage value at a particular node violate its upper limit.
(b) If the loss obtained in new iteration is greater than the previous iteration loss then the previous iteration loss is saved (or) repeat steps 1 to 5.

VII. RESULTS AND DISCUSSIONS

The methodology has been tested on IEEE 33 bus test system. This test system has real and reactive load of 3.715 MW and 2.3 MVAR respectively [29]. It is found that combined load PF of the system is about 0.85 lagging. The computer program has been implemented in MATLAB 2014 for estimation of losses with/without DG for the given test system. The fuzzy toolbox is also used to solve the optimal position problem of DG unit (Type1 and Type 3).

TABLE III
NODE VOLTAGES OF TEST SYSTEM WITH/WITHOUT DG UNIT

Node number	Node voltages without DG	Node voltage with Type 1 DG	Node voltage with Type 3 DG
1	1.000000000	1.000000000	1.000000000
2	0.997039361	0.998654349	0.999131941
3	0.982982915	0.993247363	0.996257585
4	0.975529053	0.992202789	0.997063298
5	0.968160451	0.991517465	0.998285682
6	0.949813660	0.987770407	1.001485037
7	0.946361134	0.984283150	0.998207992
8	0.941515601	0.979660855	0.993624526
9	0.935265575	0.973609229	0.987710219
10	0.929468555	0.968000431	0.982225353
11	0.928608019	0.967180532	0.981412025
12	0.927107591	0.965750144	0.979993996
13	0.921021555	0.959842463	0.974236052
14	0.918775865	0.957627812	0.972109060
15	0.917374388	0.956254483	0.970782383
16	0.916013920	0.954931635	0.969495316
17	0.914010371	0.952949948	0.967597348
18	0.913406606	0.952363422	0.967026217
19	0.996511413	0.998126964	0.998605169
20	0.992937295	0.994556829	0.995038978
21	0.992233905	0.993854055	0.994337184
22	0.991597779	0.993218410	0.993702520
23	0.979398339	0.989695290	0.992722822
24	0.972730390	0.983082611	0.986148815
25	0.969407570	0.979787464	0.982872917
26	0.947897949	0.985964576	0.999673351
27	0.945353259	0.983568876	0.997267145
28	0.933954444	0.972714394	0.986487659
29	0.925770144	0.964934940	0.978748585
30	0.922247158	0.961638965	0.975417874
31	0.918068967	0.957577271	0.971467673
32	0.917148828	0.956679505	0.970597711
33	0.916863664	0.956400843	0.970328094

Based on the proposed method the base case power flow gives the total real power loss 201.7543 kW and the fuzzy expert system gives the optimal node 6 for DG placement. The analytical method already written in section VI gives the optimal size of Type 1 and Type 3 DG unit 2.59 MVA and 3.1 MVA respectively. The percentage of loss reduction after the allocation of Type 1 and Type 3 DG unit is 49.05% and 69.44% respectively. It is also proved that the DG with the power factor equal to combined load power factor i.e. 0.85 lag gives the best result as compared to others.

TABLE IV
DG SIZES WITH OPTIMAL POWER FACTOR AND PERCENTAGE OF LOSS REDUCTION

Optimal power factor	Minimum real power loss (kW)	DG size (MVA)	Optimum location	Percentage of loss reduction
unity	102.7790	2.59	6	49.05%
0.85 lag	61.6505	3.1	6	69.44%

TABLE V
COMPARISON OF THE RESULTS OF DIFFERENT APPROACHES FOR TYPE 1 DG UNIT

Method	Optimal location	DG size (MVA)	Percentage of loss reduction
PSO [31]	6	2.567	47.40%
ABC [32]	6	3.380	44.83%
PSO [33]	6	2.570	47.37%
Proposed Fuzzy based approach	6	2.590	49.05%

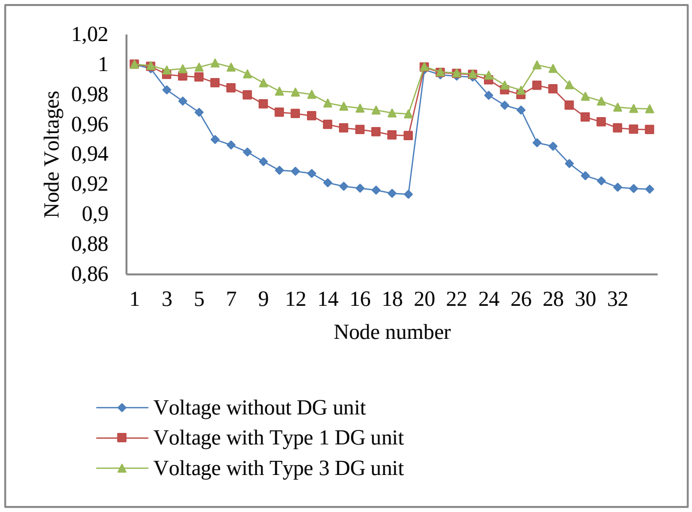

Fig.7 Voltage profile with/ without DG unit.

The voltage profile improvement and percentage of loss reductions are shown in TABLE III and TABLE IV respectively. A graphical representation of voltage profile improvement and real power losses for Type 1 and Type 3 DG unit are shown in Fig.7 and Fig.8 respectively. From the Fig.7 it is observed that the voltage profile of the given bus system is improved more by installing Type 3 DG unit as compared to Type 1 DG unit. TABLE V represents the results of the analytical methods using PSO [31], ABC [32] and other evolutionary techniques (PSO) [33] and these results are compared with the proposed fuzzy-based method to allocate Type 1 DG unit.

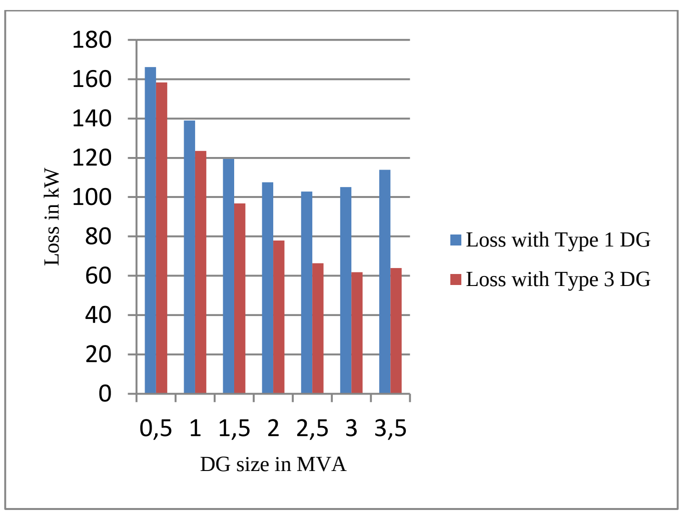

Fig.8 Real power loss reduction by Type 1 and Type 3 DG unit

VIII. CONCLUSION

This paper presents a novel fuzzy expert system to find the optimal node for DG allocation to minimize the real power losses in a radial distribution system as well as to improve the voltage profiled sizing problem is solved using an analytical method considering combined load power factor. Validity of the method is tested on IEEE 33-node radial distribution system. Results showed that appropriate size, location and power factor of a DG unit will lead a significant role to minimize the losses in distribution system.

IX. ACKNOWLEDGEMENT

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