Modified Shuffled Frog-Leaping Algorithm Based Determination of Optimal Size and Location of Distributed Generation in Radial Distribution System

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***Abstract*— The distributed generation (DG) has created a challenge and an opportunity for developing various novel technologies in power generation. DG provides multitude of services to utility and consumers. Loss reduction is one of the prime objectives for distributed generation (DG) placement in distribution system. To maximize the DG benefits, optimal placement of each DG is most important as DG benefits are site and size specific. The aim of this work is to minimize the active power loss and to improve voltage profile of overall system by optimal sizing and siting of multiple DGs. The proposed work will find the optimal value of the DG location and capacity to be connected to the existing system using Modified shuffled frog-leaping algorithm (MSFLA). The proposed work is tested with IEEE standard 33-bus radial distribution system. The whole work is programmed using MATLAB R2010a. This method has a potential to be a tool for identifying the best location and rating of DG to be installed for reducing line losses in distribution system.**

***Index Terms*— Distributed Generator, active power loss, Voltage profile, Radial Distribution system, optimization techniques, optimal size, optimal location.**

I. INTRODUCTION

Distributed generation (DG) is a small scale power generation that provides electrical power at a site closer to consumer (or consumption). A distributed generation unit can be connected directly to the consumer or to a utility's transmission or distribution system. The key element of this new environment is to build and operate several DG units near load centers instead of expanding the central generation stations located far away from the consumers to meet the increasing load demand.

The penetration of DG has increased at distribution system as it offers economical as well as technical benefits to network operator. Its benefits are size and location specific therefore more attention is given to find out the optimal size and location for DG placement such that maximum benefits can be obtained. The benefits associated with DG placements are reduction in active power loss, improved voltage profile, eliminates system up gradation, increase reliability etc. The penetration of distributed generation makes distribution network an active network. DGs are scattered within the network but are not centrally dispatchable. It uses renewable and nonrenewable energy sources such as: Wind turbines, Solar photovoltaic, Biomass energy sources, Diesel generator, fuel cells and micro turbines. Technological advancement and increase in demand due to population growth have accelerated the penetration of DG into transmission and distribution system. Also the advancement in power electronics and energy storage device for transient backup, lead the use of DG as an energy source. To avail DG benefits it should be placed at an appropriate location with suitable capacity. The losses in distribution system are high as it operates at lower voltage and higher current. The distribution network operator is accountable to reduce these losses to benefit the distribution utilities. In planning and operation of DG, active power loss reduction is considered as the most important factor.

There are various optimization techniques adopted to find optimal size and location of DG. The proposed work will find the optimal value of the DG location and capacity to be connected to the existing system using Modified shuffled frog-leaping algorithm (MSFLA).

Literature Survey

In the literature, three methods namely analytical, heuristic and optimization techniques are adopted to find the optimum size of DG. Out of which optimization techniques are most popular techniques to find optimal size of DG as it can give the best solution within short duration of time for a given distribution network. Based on power stability index optimal size and location is found out in [1], wherein, maximum power stability index (MPSI) is calculated using maximum power transfer theorem. Mixed integer non-linear programming (MINLP) formulation for DG placement in distribution network is presented in [2], wherein, Siting Planning Model (SPM) which uses Combined Loss Sensitivity, Capacity Planning Model (CPM) and Sequential Quadratic Programming are used. Dynamic programming search methods are presented in [3] for optimal placement of DG to enhance voltage stability and to reduce system power losses. A multi-objective PSO based DG placement for power loss reduction and improvement in voltage stability of radial distribution system was presented in [4], wherein, voltage stability factor (VSF) is used. Optimal location and size of DG was found out in [5] using combined genetic algorithm (GA) and particle swarm optimization (PSO), wherein, site of DG is searched by GA and its size is optimized by PSO. Priority-ordered constrained search technique was developed in [6] for DG allocation in radial distribution system. In [7] Modified Shuffled Frog-Leaping Algorithm (MSFLA) was applied for DG allocation in radial distribution system. Line loss reduction index (LLRI) and voltage profile improvement index (VPII) are used to analyze benefits of employing DG.

II. PROBLEM FORMULATION

The Wind turbine is considered as DG. A wind turbine induction generator is considered which supplies active power and absorbs reactive power. Hence value of reactive power is taken as negative and this absorbed MVAR has to be supplied by the static capacitors connected at the interfacing of wind turbine with the grid.
Real power injection at node i by optimal size of DG is found out by [8]:

$$P_i = P_{DGi} - P_{Di} \quad (1)$$

Reactive Power Consumed at i^{th} DG [8]:

$$Q_{DGi} = (0.5 + 0.04 * P_{DGi}^2) \quad (2)$$

Where, P_i = real power injection at node i
P_{DGi} =real power generation by i^{th} DG at node i
P_{Di} =real power demand at node i
Q_{DGi} =reactive power demand by i^{th} DG at node i
The reactive power absorbed by DG (Q_{DGi}) is supplied by static capacitor bank. Thereby for placement of DG we consider only the active power generated by DG.

Computational Procedure

STEP 1: Carry out Load Flow Analysis using Newton-Raphson method. Calculate total line losses.
STEP 2: DG location and capacity is computed by using modified shuffled frog-leaping algorithm (MSFLA).
STEP 3: Update the value of DG in the bus data and repeat STEP 1 and view line losses.
STEP 4: Simultaneously place DG and capacitor by using Modified Shuffled frog-leaping algorithm and repeat STEP 1 and view line losses.
STEP 5: The results obtained with DG and without DG are compared.

Objective function

Minimization of total active power loss.
Subjected to following operational constraints,

1. Penetration level: It refers to amount of energy generated as a percentage of annual consumption. Here, up to 50% penetration level is considered.
2. Voltage constraints: Voltage should be within the permissible limits. The lower and upper voltage thresholds are set at 0.92 and 1.05 p.u, respectively.
3. Constraint on DG capacity: It should not exceed the capacity of DG. DG capacity should be within permissible limits specified.

Modified Shuffled Frog-Leaping Algorithm

MSFL algorithm is a meta-heuristic method which finds the global optimal solution by performing a heuristic search. It is an evolution process in which information is exchanged globally carried by individual's memes and population. Thus it combines the benefits of the local search and global search.

MSFLA mainly based on the behavior of groups of frogs searching for the location that has maximum amount of available food. The MSFLA involves a population of possible solutions defined by a set of virtual frogs. This set of virtual frogs is partitioned into subsets known as memeplexes. The memeplexes can be perceived as a set of parallel frog cultures attempting to reach same goal. Frog leaping improves an individual frog and enhances its performance towards the goal. Within each memeplex each frog holds different ideas and the idea of each frog can be used to infect the ideas of other frogs. The process of passing information between the frogs of memeplex is known as, 'local search' or ' memetic evolution step'. After a defined number of memetic evolution steps, the virtual frogs are shuffled and reorganized, so that the quality of memeplex is improved. Shuffling enhances the memetic quality after infection and ensures the cultural evolution towards a particular interest. The process of evolution and shuffling are repeated until a required convergence is reached.

III. SOLUTION METHODOLOGY

The sequential steps are as follows [7]:

1. Begin;
2. Generate random population of P solutions (Frogs);
3. for each individual P: calculate fitness;
4. Sort the population P in descending order of their fitness;
5. Divide P into m memeplexes;
6. for each memeplex: Determine the best and worst frogs;

7. Improve the worst frog position.
8. Repeat for a specific number of iterations, End;
9. Combine the evolved memeplexes;
10. Sort the population P in descending order of their fitness;
11. Check if termination = true;
12. End;

Flowchart

The formula to improve the worst frog position in local search is given by,

$$D = rand(1) * C * (Xb - Xw) \quad (3)$$

$$new\_Xw = Xw + D \quad (4)$$

Where, Xw is the position of the worst frog in the memeplex, Xb is the position of the best frog in the memeplex, rand is a random number between 0 and 1, C is search acceleration factor equal to 2.7 [8]. If this evolution produces a better frog (solution), it replaces the older frog. Otherwise, Xb is replaced by Xg (global best) in the above equation, expressed as,

$$D = rand(1) * C * (Xg - Xw) \quad (5)$$

$$new\_Xw = Xw + D \quad (6)$$

If no improvement occurs in this case, a random frog (solution) is generated to replace the old frog,

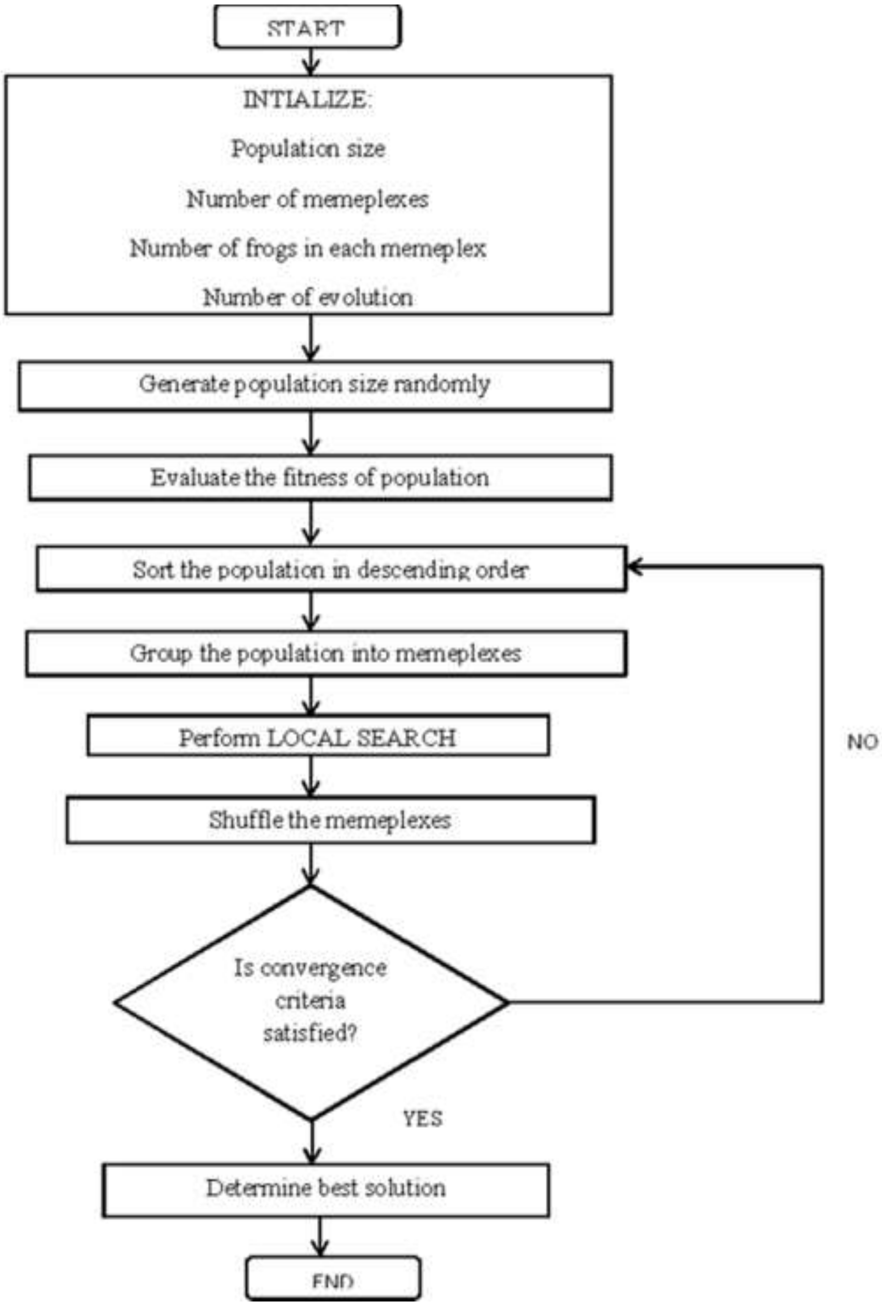

Fig. 1 flow chart of MSFLA

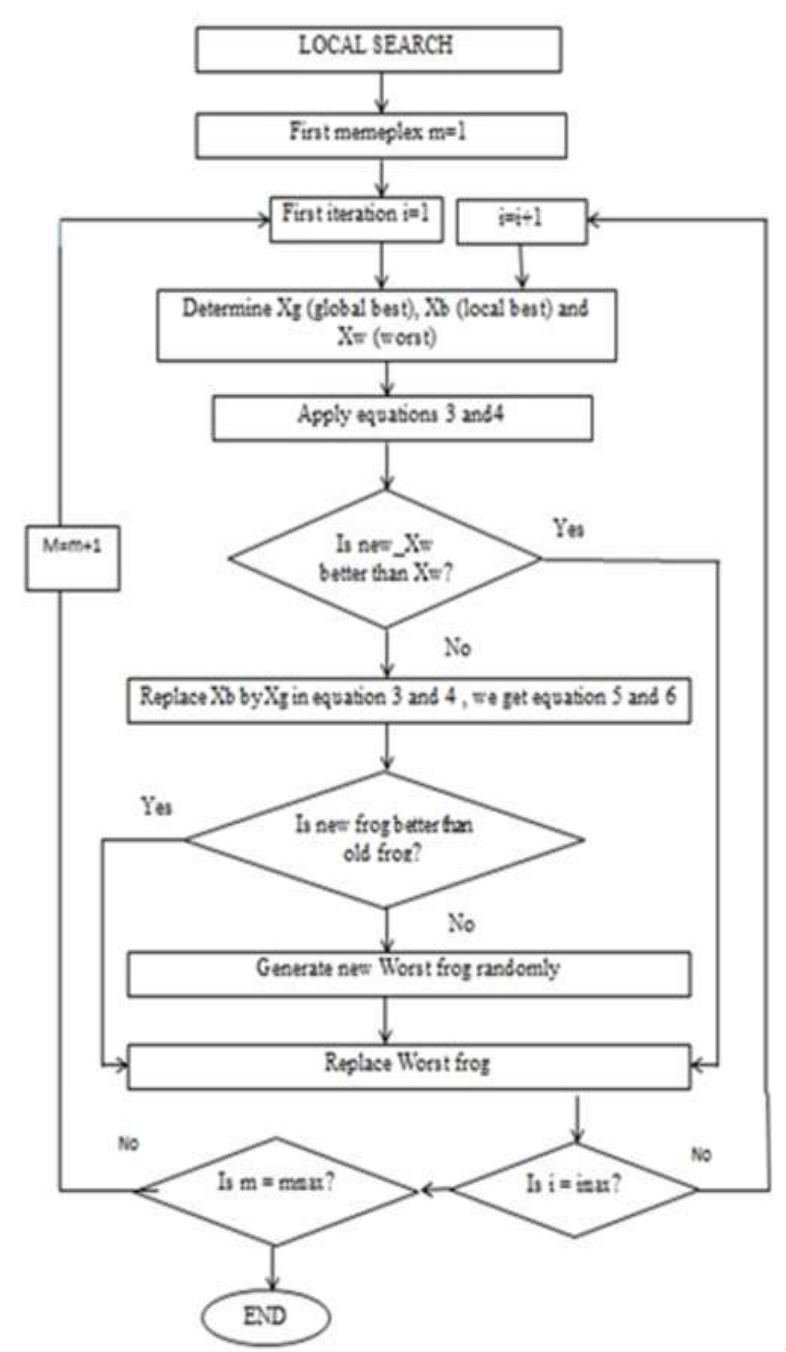

Fig. 2 flow chart of local search

Algorithm for Dg Placement Using MSFLA

STEP 1: Initialize. Write bus data and line data. Specify total number of frogs, total number of memeplexes, and number of frogs in a memeplex; specify total number of shuffling and total number of evolution. Generate Random population/frogs initially.

STEP 2: Run the load flow analysis and compute active power losses after placing each frog in appropriate location. Identify minimum loss producing frog by organizing frogs in descending order of their fitness value. Fitness value is active loss minimization. The last frog in the order is the best frog which produces minimum active power loss. This frog is also taken as global best frog initially.

STEP 3: Group frogs into memeplex. Assign grouped memeplex in bus data, run load flow and calculate total active power loss. Identify best frog (Xb) and worst frog (Xw). Carry out local search. Local search has been explained in Figure. 2 and same can be applied for DG optimal placement. Replace worst frog with the new worst frog obtained by local search and calculate fitness value.

STEP 4: Update new population. Shuffle the frogs in the memeplex. Increment shuffle count and go to STEP 2.

STEP 5: When total number of shuffling is reached, determine the best solution. End.

The algorithm is applied for three cases, they are,

1. Single DG (one frog is one DG location and size)
2. Two DG (one frog is two DGs location and size)
3. Two DG and one capacitor (one frog is two DGs location and size along with capacitor location and size)

The size and location of DG which gives minimum real power loss is the optimal size and location. In case of simultaneous placement of two DGs and a capacitor, capacitor is considered as a DG which injects reactive power.

IV. CASE STUDY AND NUMERICAL RESULTS

IEEE 33-bus radial distribution system is the test system. The total load of the system is 3.715 MW and 2.3 MVAR.

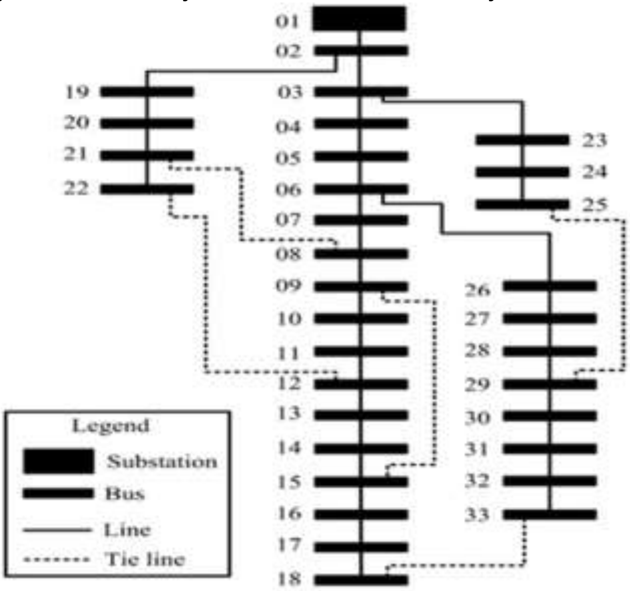

Fig. 3: IEEE standard 33-bus radial distribution system

Assumptions and Constraints

1. The lower and upper voltage thresholds are set at 0.92 and 1.05 p.u, respectively.
2. The DG size was tested in the range up to 1MW.
3. For the simultaneous capacitor placement the capacitor range is 0.15 MVAR to 1 MVAR.

Results

Table 1: Losses, Dg Location and Size

Case	Without DG (base case)	One DG	Two DG	Two DG + Capacitor
Active Power Loss (kW)	202.7	127.3	95.5	60.5
Reactive Power Loss (KVAR)	135.2	86.6	64.9	43.4
DG Location (bus number)	-	30	30 18	32 11
DG Size (MW)	-	1	1 0.5	1 0.6
Capacitor Location (bus number)	-	-	-	7
Capacitor Size (MVAR)	-	-	-	1

Comparison of Losses

CASE 1: Without DG

The total generation of system is 3.9165 MW and 2.4343 MVAR. The losses are 202.7 kW and 135.2 KVAR. This is considered as reference for loss comparison.

CASE 2: Single DG

The total generation of system is 3.8418 MW and 2.3862 MVAR. The losses are 127.3 kW and 86.6 KVAR. The reduction in active power loss is 37.2% and reactive power loss is 35.9%. This clearly shows that by penetration of DG into distribution system and by its optimal placement active power loss reduces.

CASE 3: Two DG

The total generation of system is 3.8102 MW and 2.3647 MVAR. The losses are 95.5 kW and 64.9 KVAR. The reduction in active power loss is 52.9% and reactive power loss is 52%. This clearly shows that placement of two DGs optimally will reduce active power losses further when compared to single DG case.

CASE 4: Two DG with Capacitor

The total generation of system is 3.7754 MW and 1.3433 MVAR along with a capacitor injecting 1 MVAR. The losses are 60.5 kW and 43.4 KVAR. The reduction in active power loss is 70.2% and reactive power loss is 67.9%. This clearly shows that along with two DGs if a capacitor is placed then active power losses is further reduced when compared to two DG case.

Table 2: Comparison of Losses

Cases	**Active Power Loss (kW)**	**Reactive Power Loss (KVAR)**	**% Reduction in Active power Loss**	**% Reduction in Reactive Power Loss**
Without DG (base case)	202.7	135.2	-	-
Single DG	127.3	86.6	37.2	35.9
Two DG	95.5	64.9	52.9	52
Two DG with Capacitor	60.5	43.4	70.2	67.9

Voltage Profile

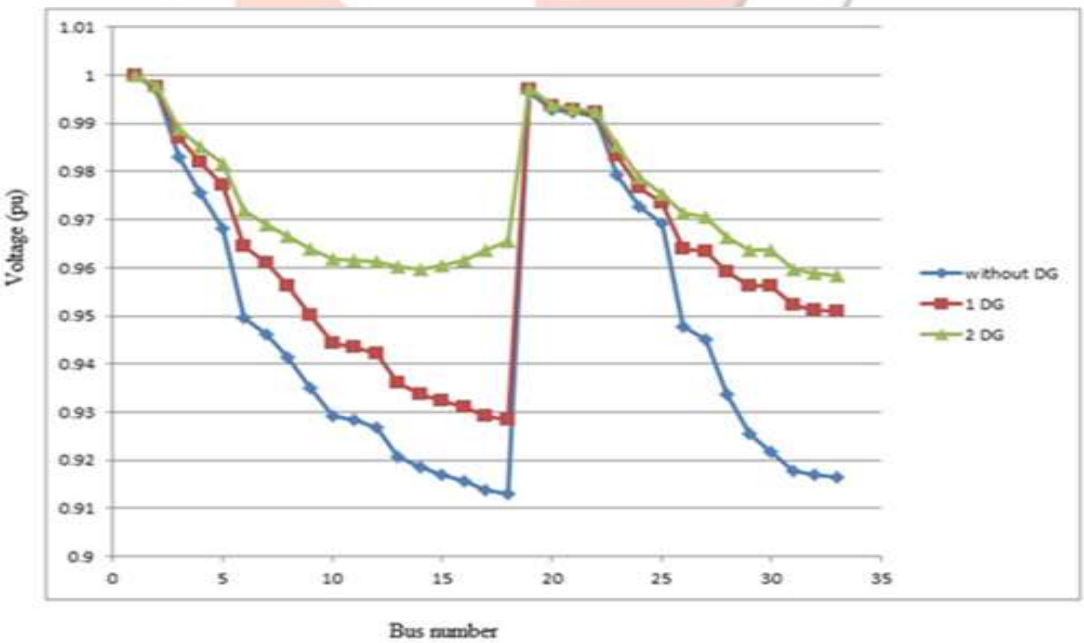

Fig. 4: Voltage Profile for DG placement only

Figure 4 gives the voltage profile of three cases, without DG, with one DG and with two DG. It can be seen from the graph that by placing one DG voltage profile has been improved compared to that without DG also, by the placement of two DG, the voltage profile has been further improved compared to that of one DG.

Figure 5 gives the comparison of voltage profile between placing of two DG and placing of two DG along with capacitor. It can be seen that voltage profile is improved with addition of a capacitor.

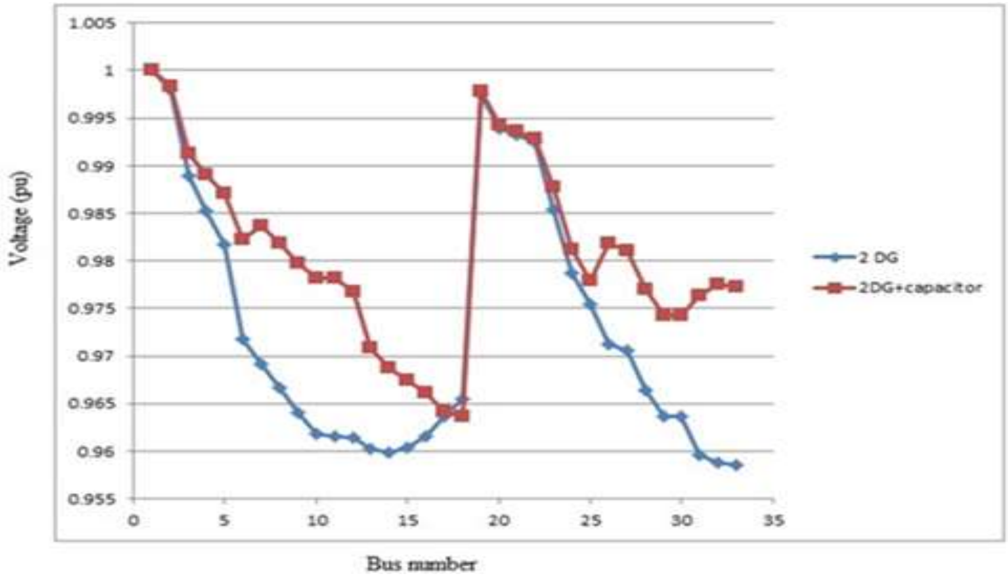

Fig. 5: Voltage Profile without/with capacitor

V. CONCLUSIONS

The penetration of DG has increased at distribution system as it offers economical as well as technical benefits to network operator. Its benefits are location and size specific therefore more attention is given to find out the optimal location and size for DG placement such that maximum benefits can be obtained. The proposed work has presented an approach to quantify some of the benefits of DG namely, real power loss reduction and also voltage profile improvement by using Modified Shuffled Frog-Leaping Algorithm (MSFLA).

The results of the proposed method as applied to IEEE 33-bus system clearly show that DG can reduce real power losses and improve the voltage profile. Both ratings and locations of DG are considered together to capture maximum benefit of DG.

In addition, it has been shown that by placing a capacitor along with DG, losses can be further reduced and voltage profile can be further improved.The proposed methodology acts as a potential tool for DG placement.

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