Optimal placement and sizing of multi distributed generators using Teaching and Learning Based Optimization

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***Abstract*-- In this paper a new optimization algorithm TLBO (Teaching and Learning Based Optimization) has been implemented to solve optimal multi Distributed Generator (DG) placement problem. This problem has been formulated for minimization of loss, capacity release of transmission lines and voltage profile improvement. To reduce search space and computational burden optimization has been done in two stages first to find the optimal locations for DG placement and latter to find the optimal size of each DG. The proposed TLBO technique has been tested on IEEE 33 bus and IEEE 69 bus radial distribution system. The results have been compared with well known algorithms in literature like GA (Genetic Algorithm) and PSO (Particle Swarm Optimization). A study on effect of DG size and power factor on system performance is done. Results showed significant reduction in power loss and line flows and significant improvement in voltage profile.**

***Index Terms*-- Distributed Generator (DG), Genetic Algorithm (GA), Multi Attribute Decision Making (MADM), Particle Swarm Optimization (PSO), Teaching and Learning Based Optimization (TLBO).**

I. NOMENCLATURE

X_{ij}	i^{th} learner's j^{th} variable.
X_{tj}	Teachers j^{th} variable.
X_{qj}	q^{th} learner's j^{th} variable
T_f	Teaching factor either 1 or 2.
$F(X_{ij})$	Objective function value for variables X_{ij}.
$F(X_{tj})$	Objective function value for teacher variable X_{tj}
M_j	Mean of j^{th} variable considering all learners.
P_{loss}^{k}	Real power loss of line k.
Q_{loss}^{k}	Reactive power loss of line k.
R_k	Resistance of line k.
X_k	Reactance of line k.
P_k	Effective real power flow through line k.
Q_k	Effective reactive power flow through line k.
$P_{LOAD}(i)$	Real power load at i^{th} bus.
$Q_{LOAD}(i)$	Reactive power load at i^{th} bus.
$P_{DG}(i)$	Real power capacity of DG placed at i^{th} bus.
$Q_{DG}(i)$	Reactive power capacity of DG placed at i^{th} bus
V^{min}	Minimum bus voltage value permitted (0.95p.u).
V^{max}	Maximum bus voltage value permitted (1 p.u.)
$MVA_k^{maxflow}$	Maximum line flow permitted (Base case line flow in the line k)
V_{mn}	Least bus voltage in the system
V_p	Voltage at p^{th} bus
V_q	Voltage at q^{th} bus
MVA_k^{flow}	MVA flow through line k
P_m	Mutation probability
P_x	Cross over probability

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II. INTRODUCTION

Distributed generation is defined as the power generation at the customer side of system. Distributed generation offers various technical and economical benefits like power loss reduction, voltage profile improvement, decreased conductor loading, reduced Right of Way (ROW), reduced cost of generation etc. Nevertheless mere inclusion of distributed generation may not always be beneficial. A DG placed at a non optimal bus may cause negative impact on the system like over voltages, conductor over loading and also increased losses. Apart from optimal location and size of DG, total distributed generation penetration into the distribution system should also be considered. High penetration of photo voltaic based DGs may cause excessive voltage harmonics and high penetration of renewable energy resources (photo-voltaic and wind turbine based DG) may cause operational difficulties due to uncertainty in power supply.

Researchers have published many papers using various mathematical and meta-heuristic techniques. Meta-heuristic techniques like GA [13], PSO [12], Harmonic search [4], Tabu search [14] have been used. Efforts have also been made to include uncertainty with respect to renewable resources using probabilistic techniques [3]. Researchers have considered different objectives for optimal DG placement like loss reduction [1], voltage stability enhancement [2], benefit of distributed generator operator [9], few authors have worked with multiple objectives a combination of three or more of the above mentioned objectives [12]. Optimal DG placement problem forms as a nonlinear optimization problem with nonlinear constraints so the best and easiest technique is to exploit meta-heuristic techniques to solve the problem. In this paper objective function is formulated as MADM (Multi

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Attribute Decision Making problem) with empirically selected appropriate weights.

[1] Teaching and Learning Based Optimization

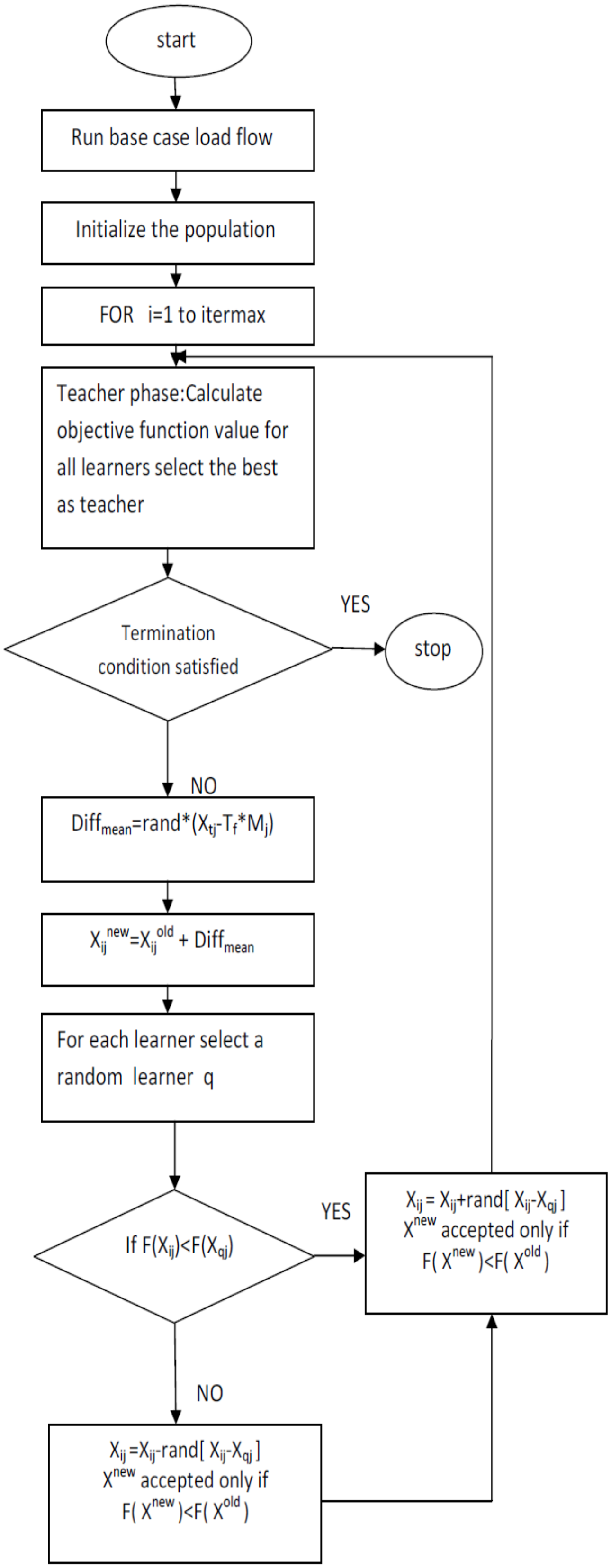

Fig 1: Flow chart for TLBO

Teaching and Learning Based Optimization (TLBO) [6] is a population based meta-heuristic algorithm which mimics teaching and learning experience between well learned teacher and a student in a class room. The main advantage of TLBO is that it does not have algorithm specific parameters unlike other techniques like GA (mutation and cross over probability), PSO (C_1,C_2,W_{max},W_{min}) etc.

In this algorithm an initial set of solutions are generated randomly called as learners. The knowledge possessed by each learner is judged by the value of objective function. The learner who possesses most knowledge (best objective function value) is treated as teacher and rest of the solutions as students. It consists of two phases.

1. Teacher phase - In teacher phase knowledge is passed from teacher (best solution) to learners.

$$Diff_{ij}^{mean} = rand\,(X_{tj}-(T_f*M_j)). \quad (1)$$

$$X_{ij}^{new} = X_{ij}^{old} + Diff_{ij}^{mean} \quad (2)$$

Replace X_{ij}^{old} with X_{ij}^{new} only if X_{ij}^{new} gives better solution than X_{ij}^{old} .

2. Learner phase- In this phase each learner tries to improve his knowledge by learning from other learners having better knowledge than him. For each learner 'i' a partner is selected randomly say 'q'

$$\text{If } F(X_{ij}) < F(X_{qj})$$

$$\text{then } X_{ij}^{new} = X_{ij}^{old} + rand*(X_{ij}^{old}-X_{qj}) \quad (3)$$

$$\text{If } F(X_{ij}) > F(X_{qj})$$

$$\text{then } X_{ij}^{new} = X_{ij}^{old} - rand*(X_{ij}^{old}-X_{qj}) \quad (4)$$

X_{ij}^{new} is accepted only if $F(X_{ij}^{new}) < F(X_{ij}^{old})$.

B. GA and PSO

Genetic algorithm and particle swarm optimization algorithm are also population based meta-heuristic algorithms. These algorithms have been successfully implemented in solving many complex non linear problems. The main drawback in population based meta-heuristic techniques is that they have algorithm specific parameters. GA has mutation probability, cross over probability, as the main parameters and PSO has inertial weights ($W_{MAX,}$ W_{MIN}) and (C1,C2) .Rate of convergence, exploration and exploitation capabilities of those algorithms depends on tuning of the parameters. Hence to get the best solution from algorithms tuning of parameters has to be done. TLBO is exceptional from this as expect initial population size it does not have any other parameters that are to be tuned.

The paper has been organized into six sections. Section II presents a brief overview of GA, PSO, TLBO and the current research approaches to solve optimal DG placement problem. In section III Vector Distribution Load Flow is discussed for the analysis of the test system under study. The optimization methodology for DG placement and DG size has been described in detail in section IV. In section V the proposed TLBO algorithm application on IEEE 33 bus and IEEE 69 bus radial distribution system has been reported and discussed in comparison with GA and PSO. The final outcome of the proposed TLBO algorithm is concluded in section VI.

III. VECTOR DISTRIBUTION LOAD FLOW

Distribution systems are all ill conditioned systems due to their highly radial structure and low X/R ratio. Hence conventional load flow techniques like Newton-Raphson and Fast Decoupled load flow techniques does not exhibit good convergence Hence vector distribution load flow(VDLF) is used. In VDLF initially line losses are assumed as zero and they are updated after each iteration after updating voltages. For convergence criteria loss mismatch is used.

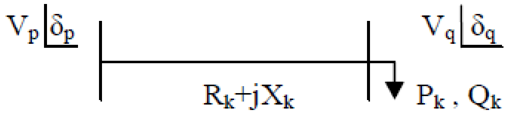

Fig :2. Line diagram

$$P_{loss}^{k}= (P_k^2 + Q_k^2)*(R_k/V_q^2) \quad (5)$$
$$Q_{loss}^{k}= (P_k^2+ Q_k^2)*(X_k/V_q^2) \quad (6)$$
$$V_q=\sqrt{(\sqrt{A} - B)} \quad (7)$$
$$B= (P_k*R_k + Q_k*X_k - 0.5*V_p^2) \quad (8)$$
$$A= (B^2- (R_k^2 + X_k^2)*(P_k^2 + Q_k^2) \quad (9)$$

The following equations are solved iteratively till the difference between the line loss of present iteration and previous iteration is less than the tolerance value taken as 0.01.

A.Modeling of DG in load flow

A DG placed at i^{th} bus is modeled as negative load at that particular bus.

$$P_{LOAD}(i) = P_{LOAD}(i) -P_{DG}(i). \quad (10)$$
$$Q_{LOAD}(i) = Q_{LOAD}(i) -Q_{DG}(i). \quad (11)$$

DG placed buses are taken as PQ buses as DG sizes are small it assumed that DGs do not have sufficient capacity to regulate bus voltages. Power factor of DGs is considered as constant and taken as 0.85 lag.

IV. OPTIMIZATION METHODOLOGY

The problem deals with finding optimal DG size and optimal bus for DG placement for loss and line loading reduction and voltage profile improvement.

Objective function-

Min $F=A*LOSS_{index} + B*VOLTAGE_{index} + C*MVA_{index}$

$LOSS_{index}= (LOSS_{with\ DGs\ placed} /LOSS_{without\ DG})$

$VOLTAGE_{index}=10*$ absolute$(1-V_{mn})$

$MVA_{index}=\max (MVA_k^{flow}{}_{with\ DG}/MVA_k^{flow}{}_{without\ DG})$

A, B, C are empirically selected weights.

Constraints:

$$V^{min} < V < V^{max}$$
$$MVA_k^{flow} < MVA_k^{maxflow} \text{ for all lines.}$$

$LOSS_{INDEX}$: The ratio of real power loss in the system with DG installed to the real power loss in the system without DG.
$VOLTAGE_{index}$: Absolute $10*(1-V_{mn})$ V_{mn} is the least bus voltage value among all the buses in the system.
MVA_{index}: Maximum ratio of MVA line flows with DG to the MVA line flows without DG considering all lines.

Optimal DG placement has two types of variables DG size and bus number. In a multi distributed generator placement number variables is equal to the twice the number of DGs .So in order to reduce the search space optimization has been run in two stages .In the first stage small DG sizes of 20% total DG penetration is considered and optimization algorithm is run to find out the set of optimal buses. In next stage optimal buses are fixed and algorithm is run to find the optimal sizes of DGs.

V. CASE STUDIES AND RESULTS

The proposed algorithm has been implemented in MATLAB 2011 installed in PC with specifications of 3 GB RAM, Intel core 2 duo processor with clock rate of 2.1GHz.
The proposed method has been tested on two IEEE Radial Distribution Systems and the parameters utilized and findings of simulated results have been reported in this section. The parameters used in applying GA, PSO, and TLBO algorithm have been represented in Table I.

TABLE I
Parameters used for GA, PSO, TLBO algorithms

Algorithm	P_{size}	Other parameters
GA	45	P_m=0.01;P_x=0.7
PSO	45	C_1=2;C_2 =2 W_{max}=0.9 ; W_{min}=0.05;
TLBO	45	None

Weights selected for objective function are 2, 2, 1 for A,B,C
Case (a) - IEEE 33 Bus Radial Distribution System
The IEEE 33 bus system has a total load of 3.715MW and 2.3 MVAR with real and reactive power loss of 202 KW [8] and 134.9 KVAR.
The single line diagram of the test system is as shown in the Figure 3.

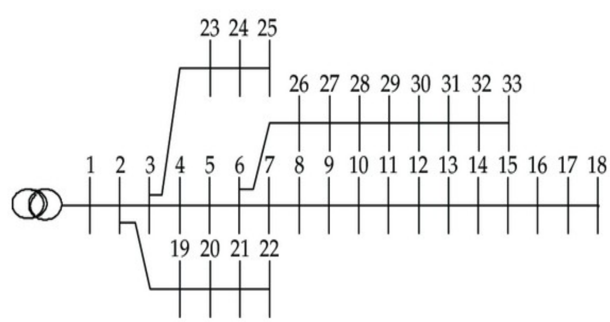

Fig 3: IEEE 33bus radial distribution system [8]

TABLE II
Optimal DG Locations and Optimal DG sizes

	GA	PSO	TLBO
P_L(KW)	65.6	52.5	41.5
Q_L(KVAR)	43.2	34.7	27.6
V_{mn} (p.u)	0.9573	0.9687	0.972
Locations	17,30,31	31,32,14	30,31,14
Sizes(MW)	0.26,0.38,0.4	0.5,0.3,0.5	0.5,0.5,0.5

Table II shows that TLBO could optimally select the buses which could allow maximum DG penetration of 1.5MW, though GA also could identify buses which allowed maximum DG penetration, loss and voltage figures show that TLBO results are superior to GA and PSO. Improvement in the voltage profile of the system can be observed from figure 4

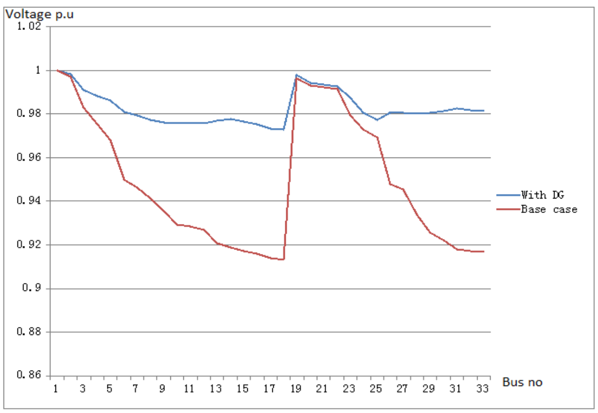

Fig 4: Voltage profile of IEEE 33 bus system with and without DG

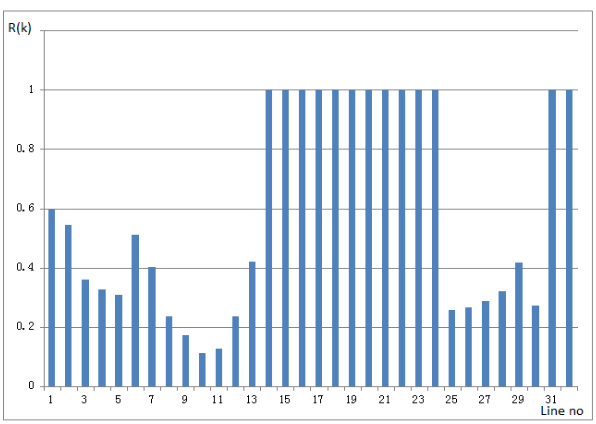

Fig 5: Ratio of MVA line flows with and without DG for all lines for IEEE 33bus system

Figure 5 shows loading of lines as a fraction of base case line loading. Transmission capacity release can be interpreted from figure 5. Maximum loading is equal to the base case line loading and loading of most of the lines is less than the base case hence transmission capacity release has been achieved.

Case (b)-IEEE 69 Bus Radial Distribution System

IEEE 69 bus system has a total load of 3.8 MW and 2.69 MVAR with real and reactive power loss of 262 KW [8] and 117KW.

The single line diagram of the test system is as shown in Figure 6

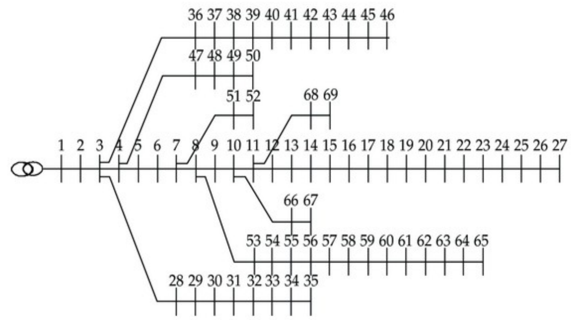

Fig 6: IEEE 69 bus radial distribution system [8]

TABLE III
Optimal DG Locations and Optimal DG Sizes

	GA	PSO	TLBO
P_L(KW)	43.69	41.78	41.67
Q_L(KVAR)	21.39	19.57	19.5
V_{mn} (p.u)	0.9707	0.962	0.97
Locations	16,54,47,49	18,11,51,52	17,11,51,52
Sizes (M.W)	0.34,0.422, 0.5, 0.5	0.5,0.5,0.5,0.5	0.5, 0.5, 0.5, 0.5

Table III shows that the TLBO algorithm could optimally select the buses for maximum DG penetration of 2 MW with out violating voltage and line flow constraints. GA and PSO algorithms could also identify DG sizes and locations for loss reduction and voltage improvement but results show that TLBO performance is superior to GA and PSO.

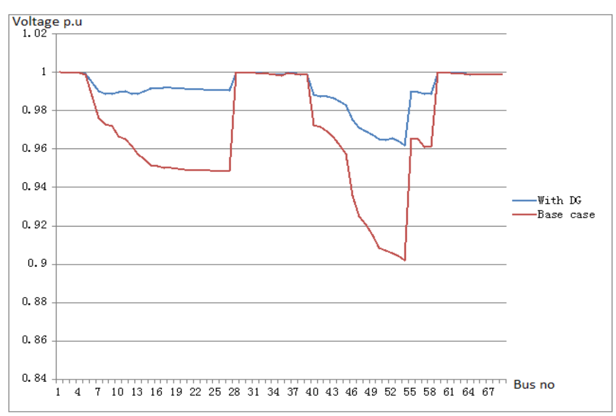

Fig 7: Voltage profile for IEEE 69 bus system with and without DG cases

The voltage profile improvement of the system by DG placement for 69 bus system can be seen in figure 7.

B. Studying the effect of DG power factor on system losses and voltage profile:

The effect of DG power factor on system loss and voltage profile is studied on IEEE 33 bus system, keeping the number of DG's and their KVA sizes constant. The effect of DG power factor on voltage profile can be studied from fig 8

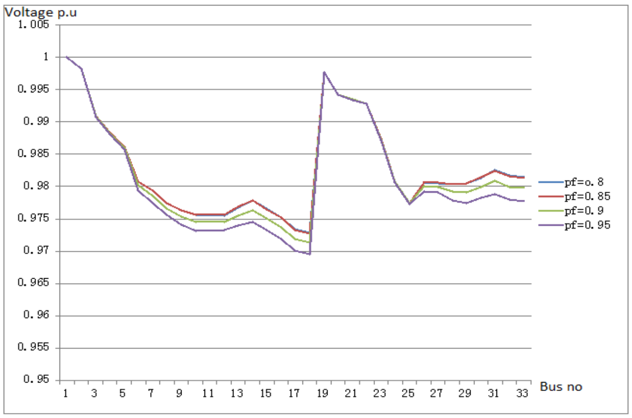

Fig 8: Variation of voltage profile for various power factors

For same KVA size *lower* power factor implies greater reactive power injection hence it aids in voltage profile improvement. This trend is observed only up to certain power factor after that voltage profile improvement is not much significant, this is because as the share of reactive power increases real power requirement of the buses is met by the grid, hence line flows and voltage drop increases. So, there exists an optimal DG power factor at which the system voltage profile is best. This optimal power factor is closer to system power factor.

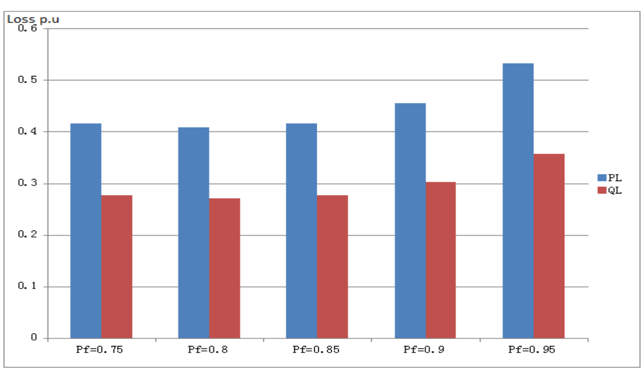

Fig 9: Variation of system loss with power factor

DG has to inject an optimal combination of real and reactive power, any deviation from this the buses will draw more real or reactive power from the grid depending on the DG power factor. This will increase the line flows and system losses. For the test system the optimal power factor is between 0.8 and 0.85.

C. Effect of DG size on the system losses and voltage profile

The effect of DG size is studied on IEEE 33 bus system by varying number of DGs and their sizes keeping total DG penetration constant.

For a given DG penetration if more number of smaller DGs are used there is chance for improving voltage profile of more number of buses and also power of smaller DGs is used locally hence power flows in lines is less so there would be less losses and improved voltage profile. If the size of DG is very small buses has to taken power from adjacent DGs and main grid hence power loss will increase. Hence size and number of DG's should be optimal

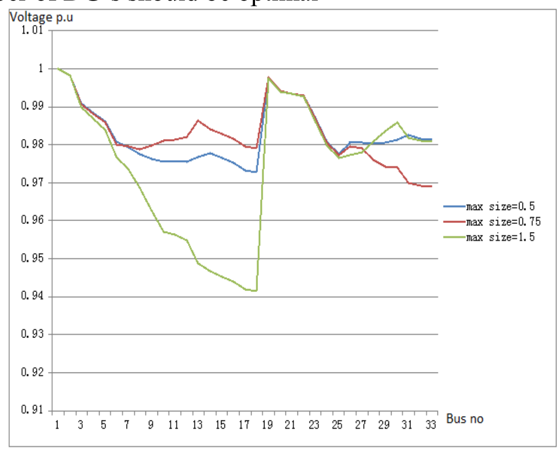

Fig 10: Voltage profile for various maximum DG sizes

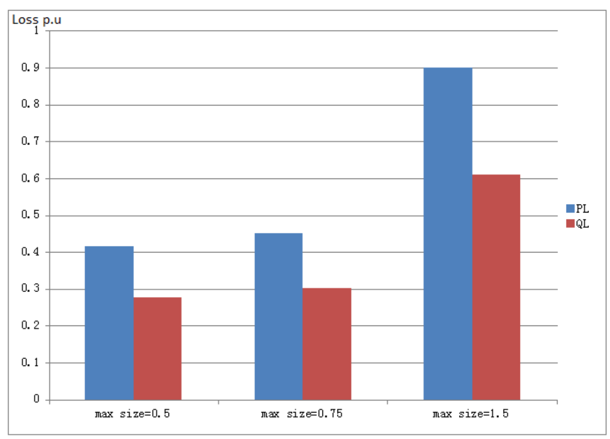

Fig 11: Variation of system loss with maximum DG size

VI.CONCLUSIONS

Optimal DG placement problem is attempted using three algorithms GA, PSO, TLBO. It is observed that TLBO gave better results for both the test cases followed by PSO and TLBO. Effect of DG power factor and DG size on system performance is also studied. Optimal DG placement resulted in reduced system losses, improved voltage profile, and reduced line flows. DG operating at optimal power factor resulted in best performance in terms of loss reduction and voltage profile improvement. Increase in power factor of the DG resulted in lower voltage profile due to the decrease in reactive power support. Similarly decrease in power factor of DG resulted in better voltage profile. This trend is observed up to optimal power factor after which there is no significant improvement in system voltage. Least loss is obtained at optimal DG power factor which is governed by system load, any variation from this power factor will increase loss

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