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RESEARCH ARTICLE OPEN ACCESS

AN EFFECTIVE GTO ALGORITHM BASED COST-BENEFIT ANALYSIS OF DISCOS BY OPTIMAL ALLOCATION OF DG AND DSTATCOM IN A REDIAL DISTRIBUTION NETWORK

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ABSTRACT

Electric power Distribution Companies (DISCOs) is playing a major role for delivering active power from distribution substations to customers with lover cost, high reliability and voltage stability. In the DICOs, the transmission lines are redial in nature; all buses are containing the load and no generating buses. Therefore, voltage at each bus is minimized, loss of the network and voltage deviation is increased, and cost and benefit of the DISCOs and consumers are minimized. This paper maximizes the cost–benefit, and voltage stability of DISCOs is improved by optimally considering the Distributed Generation (DGs) and DSTATCOM. Here, applied a novel comprehensive Group Teaching Optimization (GTO) algorithm for planning DG units and DSTATCOM which considers both the Distribution Company's and the DG Owner's (DGO) profits simultaneously. The proposed GTO is applied to a 33-node test system and simulations are carried out using MATLAB platform and results show the applicability of the GTO in the DISCOs.

I. INTRODUCTION

Generally, the prime objective of the Distribution Companies (DISCOs) is to supply the reliable electric energy to the consumers and satisfy required load demand of the Radial Distribution Network (RDS). Due to the fact that the majority of loads connected to the distribution network is inductive in nature, there exists possibility of higher energy loss and lower reliability in the distribution feeder sections [1]. Any outages in the part of distribution system, will heavily affect the continuous and reliable supply of power to the end consumers. Therefore, it is essential for distribution system planners to design, operate, and maintain distribution system with higher reliability and lower energy loss. For this purpose, compensation devices are installed in the distribution network so as to achieve higher technical and economic benefits [2],[3].

The researchers developed various compensating devices and approaches to maximize the reliability, voltage stability and profit of DISCOs udder competitive environment. Artificial immune systems [4] approach has to enhance the voltage and reduce the network loss of the system. The author DSTATCOM is installed optimally using artificial immune system with less installation cost. Biogeography Based Optimization [5] method has been applied to solve the same problem. Here, DG units were optimally allocated to minimize the network loss. The Salp Swarm Algorithm [6] also applied to solve the same problem.

Renewable Distributed Generation and Capacitor Units [7] have been fudged with the RDS to reduce the network loss and improve the stability of the network. An analytical optimization method has been implemented in a in public medium voltage distribution networks. The DG and D-STATCOM [8] have been integrated with the RDS to reduce the network loss and improve the stability of the mitigated.. Here, VSI and Loss Sensitivity Factor has been applied to find optimal location and value of DG and D-STATCOM.

Under Competitive Environment, the PSO algorithm [9] has been applied to find the DISCOs cost and benefit of DG owners in RDS. The PSO was optimally allocated the value and size of DG and Capacitor units. Here, installation cost, operating cost and maintenance cost of both DG and capacitor was taken in account.

A hybrid Weight Improved Particle Swarm Optimization with Gravitational Search algorithm [10] has been proposed to analyse the cost-benefit of DISCOs. The multiple DG and capacitor units are optimally implemented using the projected method and results ware compared with other methods. Elephant herding optimization algorithm [11] has been applied to analyse cost and benefit by installing DG units. The benefits ware analysed with different power factors. The energy storage systems and DG units has been used to maximized the profit of DISCOs. The storage level and location and size of DG were optimized by PSO method [12]. A hybrid oppositional social engineering differential evolution with Lévy flights approach [13] was applied to solve the same problem.

Modified GA with decision-making analysis [14] has been implemented to find benefit between DISCOs and DG owners. Different types of DGs were interconnected to determine the benefits of both DISCOs and DG owners. Moth – Flame Optimization approach [15] has been applied to improve the profit of DISCOs by optimally considering the network reconfiguration, DGs and Capacitors. A classical Consumer Payment Index and Local Marginal Price [16] was used to maximize the DISCOs profit in a mesh network. The simulations have been analysed using DG units.

The optimal power flow [17] method has applied to enhance the profit of DISVOs. The authors considering the production and transmission cost of the electricity market. A fuzzy logic with e-constraint method [18] has been projected to maximize the DISCOs profit. Here, short-term scheduling, energy storage system and active network management was considered to obtain the nursery solutions. Single and Multiple DSTATCOM has been interconnected to analyse the cost and benefit of DISCOs Ant-Lion Optimization Algorithm [19]. When considering the two DSTATCOM connected optimally, the profit of DISCOs has been improved. When single and three DSTATCOM connected to the network, the profit was reduced due to more installation and maintenance cost of DSTATCOM.

In this paper, an intelligent soft computing technique of Group Teaching Optimization (GTO) algorithm is applied to maximise the reliability and analyse the Cos-benefit of DISCOs in a competitive energy market. The DSTATCOM and DG units are interconnected optimally to compensate the reliability of the proposed test system. The searching operators of GTO are having more ability to determine best location and size of DSTATCOM and DG units. It effectively maximizes the DISCOs profit and satisfying the standard operating constraints in electricity market. The IEEE33 node test system is taken to check the validity of GTO method.

II. PROBLEM FORMULATION

The costs and benefits of DISCOs are determined using GTO approach by properly connecting both DGs and DSTATCOM with optimal values.

II. 1 OBJECTIVE FUNCTION

The objective of the proposed work is maximize the profit of DISCOs

Max Profit = Benefits - Investments (1)

Profit = Benefits from DG and DSTATCOM - Cost of DG and DSTATCOM (2)

$$Profit = B_1 + B_2 - \{C_1 + C_2 + C_3\} \tag{3}$$

II.2 BENEFIT EVALUATION OF DISCOS

Benefits of Active power demand reduction from distribution line

Energy sold to the electricity market (Grid) during ΔT time segment,

$$B_1 = \sum_{i=1}^{NDG} K_{DGi} \times EP_G \times \Delta T \tag{4}$$

If IR is the interest rate and IF the inflation rate, then the present worth factor can be represented as:

$$Present\ Worth\ Factor,\ \beta^t = \sum_{t=1}^{n} \left(\frac{1+IF}{1+IR}\right)^t \tag{5}$$

The present worth value of electricity generated from DG by the distributed company can be calculated as:

$$PWV(B_1) = \sum_{i=1}^{NDG} K_{DGi} \times EP_G \times \Delta T \times \beta^t \tag{6}$$

Benefits of Loss reduction

$$B_2 \sum_{i=1}^{NDG} \sum_{j=1}^{NCap} \Delta LOSS_{ij} EP_G \Delta T \tag{7}$$

He present worth value of loss reduction revenue in a planning horizon can be calculated as:

$$PWV(B_2) = \sum_{i=1}^{NDG} \sum_{j=1}^{NCap} \Delta LOSS_{ij} \times EP_G \times \Delta T \times \beta^t \tag{8}$$

II.3 COST EVALUATION OF DISCOS

Investment cost of DG and DSTATCOM

$$C_1 = \sum_{i=1}^{NDG} K_{DGi} \times IC_i + \sum_{i=1}^{NCap} K_{DSTATCOM} \times IC_j \tag{9}$$

Operating Cost of DG and DSTATCOM

$$C_2 = \sum_{i=1}^{NDG} [K_{DGi} \times OC_i] \times \Delta T \tag{10}$$

The present worth value of operating cost in a given planning year can be calculated as:

$$PWV(C_2) = \sum_{i=1}^{NDG} [K_{DGi} \times OC_i] \times \Delta T \times \beta^t \tag{11}$$

Maintenance Cost of DG and DSTATCOM

$$C_3 = \left[\sum_{i=1}^{NDG} (K_{DGi} \times IC_i) \times MC_{DGi} + \sum_{i=1}^{NCap} (K_{DSTATCOM} \times IC_j) \times MC_{DSTATCOM}\right] \tag{12}$$

The present worth value of this annual cost in the planning period is calculated as:

$$PWV(C_3) = \left[\sum_{i=1}^{NDG} (K_{DGi} \times IC_i) \times MC_{DGi} + \sum_{i=1}^{NCap} (K_{DSTATCOM} \times IC_j) \times MC_{DSTATCOM}\right] \times \beta^t \tag{13}$$

II.4 SYSTEM CONSTRAINTS

a. *Power balance constraints*

$$P_i = \sum_{j=1}^{N} V_i V_j \left[G_{ij}\cos(\delta_i - \delta_j) + B_{ij}\sin(\delta_i - \delta_j)\right] \forall i = 1,2,3,\ldots\ldots N \quad (14)$$

$$Q_i = \sum_{j=1}^{N} V_i V_j \left[G_{ij}\sin(\delta_i - \delta_j) - B_{ij}\cos(\delta_i - \delta_j)\right] \forall i = 1,2,3, N \quad (15)$$

b. *Voltage limits*

Voltage constraint at each bus (±5% of rated voltage) must be satisfied

$$|V_i|^{min|V_i||V_i|^{max}} \qquad \forall i \in N \quad (16)$$

c. *Current limit*

The current in distribution lines should not exceed from their ratings:

$$I_i \le I_i^{Rated} \qquad \forall i \in N_{Br} \quad (17)$$

d. Size of the DG and DSTATCOM

The sizes of DSTATCOM units must be within the permitted size limit, which is listed below:

$$P_{min}^{DSTATCOM} \le P^{DSTATCOM} \le P_{max}^{DSTATCOM} \quad (18)$$

$$Q_{min}^{DSTATCOM} \le Q^{DSTATCOM} \le Q_{max}^{DSTATCOM} \quad (19)$$

III. SOLUTION METHODOLOGY

III.1 PROPOSED GTO ALGORITHM

The proposed GTOA is considered as an idea of excellence targeting to improve the learning skills and knowledge of the entire class by simulating the group teaching process. As there are various differences among students, considering those differences is an important factor in implementing the group teaching mechanism and also it is rather complicated in practice. Hence considering the above is an essential criterion in students learning process. The four rules of GTO are properly reported in the reference [20, 21] and structure of the GTO is shown in Figure 1.

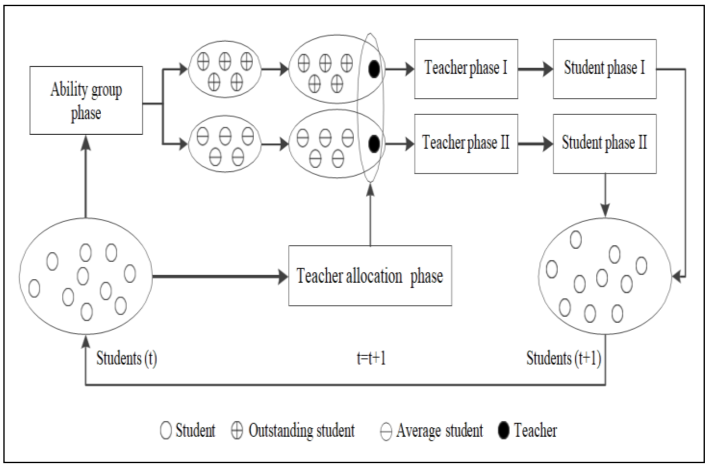

Figure 1: Framework structure of the GTO algorithm
Source: Authors, (2025).

This GTO has four phases and are mathematically represented as follows [17].

III.1.1 Ability grouping phase

Without loss of generality, the knowledge of the whole class is assumed to be in normal distribution. The normal distribution can be defined as 6.

$$f(x) = \frac{1}{\sqrt{2\pi\delta}} e^{\frac{-(x-u)^2}{2\delta^2}} \quad (20)$$

III.1.2 Teacher phase

The knowledge of the students are obtained using teacher phase -1 and Teacher phase -2 are mathematically defined as

Teacher phase I

$$x_{teacher,i}^{t+1} = x_i^t + a \times \left(T^t - F \times (b \times M^t + c \times x_i^t)\right) \quad (21)$$

$$M^t = \frac{1}{N}\sum_{i=1}^{N} x_i^t \quad (22)$$

$$b + c = 1 \quad (23)$$

Teacher phase II

$$x_{teacher,i}^{t+1} = x_i^t + 2 \times d \times (T^t - x_i^t) \quad (24)$$

Where *d* is a random number in the range [0,1].

Additionally, a student's knowledge acquisition through the teacher phase may be Limited or lesser.

$$x_{teacher,i}^{t+1} = \begin{cases} x_{teacher,i}^{t+1}, f\left(x_{teacher,i}^{t+1}\right) < f(x_i^t) \\ x_i^t, \quad f\left(x_{teacher,i}^{t+1}\right) \ge f(x_i^t) \end{cases}$$

(25)

III.1.3 Student phase

*T*he student phase of the GTO is represented as

$$x_{teacher,i}^{t+1} = \begin{cases} x_{teacher,i}^{t+1} + e \times \left(x_{teacher,i}^{t+1} - x_{teacher,j}^{t+1}\right) + g \times \left(x_{teacher,i}^{t+1} - x_i^t\right), f\left(x_{teacher,i}^{t+1}\right) < f\left(x_{teacher,j}^{t+1}\right) \\ x_{teacher,i}^{t+1} - e \times \left(x_{teacher,i}^{t+1} - x_{teacher,j}^{t+1}\right) + g \times \left(x_{teacher,i}^{t+1} - x_i^t\right), f\left(x_{teacher,i}^{t+1}\right) \ge f\left(x_{teacher,j}^{t+1}\right) \end{cases}$$

(26)

In addition, a student can use it effectively and may not acquire knowledge at the student phase. an example can be taking the minimal problem

$$.x_i^{t+1} = \begin{cases} x_{teacher,i}^{t+1}, f\left(x_{teacher,i}^{t+1}\right) < f\left(x_{student,i}^{t+1}\right) \\ x_{student,i}^{t}, f\left(x_{teacher,i}^{t+1}\right) \ge f\left(x_{student,i}^{t+1}\right) \end{cases} \quad (27)$$

III.1.4 Teacher allocation phase

Based on the defined fourth rule of teacher allocation phase can be expressed as.

$$T^t = \begin{cases} x_{first}^t, & f\left(x_{first}^t\right) \le f\left(\frac{x_{first}^t + x_{second}^t + x_{third}^t}{3}\right) \\ \frac{x_{first}^t + x_{second}^t + x_{third}^t}{3}, & f\left(x_{first}^t\right) > f\left(\frac{x_{first}^t + x_{second}^t + x_{third}^t}{3}\right) \end{cases}$$

(28)

III.2 IMPLEMENTATION OF GTO ALGORITHM TO MAXIMIZE THE DISCOS PROFIT

The following steps are used for optimal allocation and sizing of combined DG and DSTATCOM to evaluate the profit of DISCOs in a competitive electricity market using GTO algorithm. The proposed approach also does the various processes such as installation cost, operating cost and maintenance cost of the DG and DSTATCOM, Revenue, Power loss minimization, node voltage enhancement, optimal location and sizing of DG and DSTATCOM in radial distribution system:

1. Read the line, bus and load data of RDS, Installation cost, operating cost and maintenance cost of DG and DSTATCOM, Interest rate, Inflation rate, Market price and Planning period.
2. Run the distribution power flow and calculate the real and reactive power loss using exact loss formula for base case.
3. Fix number of DG and DSTATCOM are to be used to in Radial Distribution System.
4. Initialize the parameters of GTO algorithm such as Population, dimension, maximum no of iteration number, lower bound and upper bound (node and size of DG and DSTATCOM respectively).
5. Set iteration=1
6. Calculate fitness (i.e. loss and profit of DISCOs in network) for each moth by placing DG and DSTATCOM at their respective buses.
7. Evaluate the objective functions of each moth and determine the profit of DISCOs.
8. Update the position of Teacher phase and save the best fitness values in an array
9. Update the record of student phase and the flames are arranged based on their fitness values
10. Compute the present position of teacher phase.
11. Check the all constrains are satisfied, if yes move to next step, else go to step 6.
12. Check If the number of iteration process is equal to maximum number of iterations, go to step 13. Otherwise go to step 5.
13. Display the global best solution of various cost and DISCOs profit and STOP the program.

IV. RESULTS AND DISCUSSION

The ability of the proposed GTO algorithm is tested on IEEE-33 node test system. The projected algorithm efficiently optimizes the system parameters to achieve the optimal solutions which is obtain the maximum profit with less network losses. The optimization process has been approved out in MATLAB version R2021a environment on an Intel core i3 PC with 2.10 GHz speed and 4GB RAM. Generally, first bus is taken as reference bus and as connected to the substation (S/S) for 33 node test system. The control parameters of GTO are given in Table 1. The one-line diagram of 33 node RD network is displayed in fig.1. the line data, bus data and system demand are taken from reference [12]. The distribution load flow analysis has been used for network solution in each of the cases.

Table 1: Control parameters of GTO

Parameters	Value
Population Size	50
Number of Variables	10
Random Number	0 to 1
Maximum Number of iteration	500

Source: Authors, (2025).

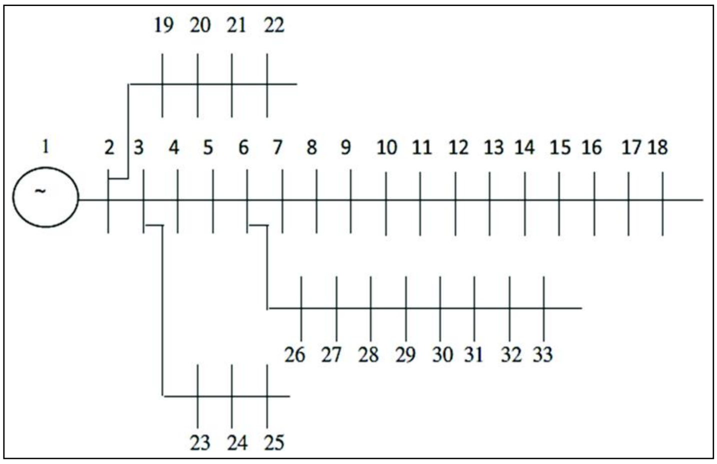

Figure 2: Single Line Diagram of IEEE-33 node radial distribution test system.
Source: Authors, (2025).

The DSTATCOM and DG placement are progressed for a planning period of 10 years. Optimal allocation is made to improve the voltage stability and profit of DISCOs. The projected GTO is properly optimized the location and size of the DG and DSTATCOM. The proposed GTO methodology has been applied to maximize the DISCOs profit considering three different test cases such as

Case 1: Profit of DISCOs considering Single DSTATCOM
Case 2: Profit of DISCOs considering two DSTATCOMs
Case 3: Profit of DISCOs considering both DG and DSTATCOM

In test case 1, single DSTATCON is considering with operating limits of 0 to 2MVAr capacity. The GTO operators (Teacher phase 1 & 2, Student phase and Teacher allocation phase) are efficiently turning the best location and required value of DSTATCOM to injector observe the reactive power to the network to enhance the voltage profile, system losses and maximized profit of DISCOs. The Simulation results of DISCOs considering single DSTATCOM is numerically reported in Table 2.

Table 2: Simulation results of DISCOs considering single DSTATCOM.

Parameters	**Optimized variables, Various costs, Benefits and Profit of DISCOs**		
	Base Case	ALO	GTO (Proposed)
Optimal location and size of DSTATCOM in MVAr	--	30 1.258	26 1.1256
P_{loss} (kW)	210.99	151.36	145.67
Q_{loss} (kVAr)	143.13	103.98	101.85
Investment cost of DSTATCOM (\$) $\times 10^5$	--	0.6290	0.57404
Maintenance cost of DSTATCOM (\$) $\times 10^5$	--	0.5284	0.49000
Total cost of DSTATCOM (\$) $\times 10^6$	--	0.1157	0.106404
c_{PP}(\$) $\times 10^6$	14.16	13.94	13.91
c_{PW}(\$) $\times 10^6$	--	0.2163	0.2256
Profit of DISCOs (\$) $\times 10^6$	--	0.1006	0.11919
V_{min} (p.u)	0.9038	0.9165	0.92051

Source: Authors, (2025).

The best location and tuned value of single DSTATCOM is 26 and 1.1256 MVAr respectively the minimum voltage and network real power loss is 0.92051 (p.u) and 145.67 KW respectively. The total profit of DISCOs is \$ 0.11919×10^6. The voltage profile, power loss and DISCO profit are effectively improved then the base case and ALO method. The power loss minimization is 30.95% is then base case and profit is 12.51\$ is improved then the ALO algorithm.

Similarly in case 2, two DSTATCOMs are consider to improve the profit of DISCOs. The upper and lower bounds of DSTATCOM are 0 to 5 MVAr respectively. The searching operators of GTO are effectively optimized the locations and sizing of DSTATCOMs. The simulation results of case 2 is displayed in Table 3. The optimized allocation and size of DSTATCOMs are 8, 30 and 3.657 MVAr, 1.054 MVAr respectively. The minimum voltage and network real power loss is 0.9589 (p.u) and 136.75 KW respectively. The total profit of DISCOs is \$ 0.12709×10^6 respectively.

Table 3: Simulation results of DISCOs considering Two DSTATCOMs.

Parameters	**Optimized variables, Various costs, Benefits and Profit of DISCOs**		
	Base Case	**ALO**	**GTO (Proposed)**
Optimal location and size of DSTATCOM in MVAr	--	(12) 4.659, (30) 1.063	(8) 3.657, (30) 1.054
P_{loss} (kW)	210.99	141.83	136.75
Q_{loss} (kVAr)	143.13	96.50	90.21
Investment cost of DSTATCOM (\$) $\times 10^5$	--	0.7640	0.7458
Maintenance cost of DSTATCOM (\$) $\times 10^5$	--	0.6418	0.6123
Total cost of DSTATCOM (\$) $\times 10^6$	--	0.1406	0.13581
c_{PP}(\$) $\times 10^6$	14.16	13.91	13.89
c_{PW}(\$) $\times 10^6$	--	0.2488	0.2629
Profit of DISCOs (\$) $\times 10^6$	--	0.1082	0.12709
V_{min} (p.u)	0.9038	0.9303	0.9589

Source: Authors, (2025).

From the Table 3, the power loss minimization is 35.19 % improved then the base case value and DISCOs profit 18.01 % is improved then the ALO approach. When considering the two DSTATCOMs, voltage at each bus, VSI, power loss minimization and profit of DISCOs are improved the single DSTATCOM is installed in the proposed distribution network. Proper location and optimal value of DSTATCOMs are effectively improves the system stability and benefits of distribution companies.

In case 3, a single DSTATCOM with DG unit is consider to further improve the profit of DISC Os. The DG unit play a very important roll for maximize the DISCOs profit and minimize the real power loss of the projected test system. When DG unit and DSTATCOM implemented in the RDS, the real and reactive power are injected in the network. So voltage profile and power loss minimization are efficiently minimized. The installation cost, operating cost and maintenance cost of DISCOs are increased due to considering DG unit.

The projected GTO approach properly optimizes the location and size of DG and DSTATCOM to simultaneity maximize the profit and minimize the total cost of DISCOs. The optimized location and sizing of DG and DSTATCOM is 8, 26 and 1.4704 MW, 0.9481 MVAr respectively.

Therefore, voltage at each bus, voltage deviation and VSI are efficiently improved. The improved voltage and VSI are compared with base case and ALO algorithm and also displayed in Table 4 and 5. The graphical comparison of voltage profile and VSI with base case and ALO algorithm is given in fig 3 and fig. 4. From the Figure 3 and 4, the voltage level stability of majority busses are improved.

Table 4: Comparison of Voltage profile of 33-node test system.

Bus No.	**Base case**	**GTO (Proposed)**	**ALO**
1	1.0000	1.0000	1
2	0.9970	0.99828	0.99825
3	0.9829	0.99173	0.99064
4	0.9754	0.98935	0.98795
5	0.9680	0.98726	0.98553
6	0.9495	0.98263	0.97968
7	0.9460	0.98136	0.97807
8	0.9323	0.98031	0.98108
9	0.9260	0.9795	0.97507
10	0.9201	0.98183	0.9695
11	0.9192	0.98191	0.96868
12	0.9177	0.9822	0.96724
13	0.9115	0.98138	0.96139
14	0.9092	0.9798	0.95922
15	0.9078	0.98054	0.95787
16	0.9064	0.98197	0.95656
17	0.9043	0.98585	0.95462
18	0.9037	0.98808	0.95404
19	0.9965	0.99739	0.99772
20	0.9929	0.99061	0.99415
21	0.9922	0.98896	0.99344
22	0.9916	0.98658	0.99281
23	0.9793	0.98867	0.98708
24	0.9726	0.98293	0.98046
25	0.9693	0.9805	0.97717
26	0.9475	0.98235	0.97844
27	0.9450	0.98209	0.97596
28	0.9335	0.98157	0.9649
29	0.9253	0.98086	0.95696
30	0.9217	0.98202	0.95352
31	0.9176	0.98332	0.9495
32	0.9167	0.98406	0.94861
33	0.9164	0.98539	0.94834

Source: Authors, (2025).

Table 5: Comparison of VSI of 33-node test system.

Bus No.	**Base case**	**GTO (Proposed)**	**ALO**
1	1	1	1
2	0.98811	0.9931	0.99299
3	0.93213	0.96693	0.96273
4	0.90479	0.9896	0.95261
5	0.87755	0.96259	0.94334
6	0.81082	0.95646	0.92098
7	0.80059	0.94726	0.91507
8	0.75445	0.9303	0.92589
9	0.73494	0.92956	0.90374

10	0.7165	0.92752	0.8833
11	0.71397	0.92926	0.88048
12	0.70927	0.95797	0.87526
13	0.69018	0.95528	0.85408
14	0.68344	0.93296	0.84657
15	0.67918	0.92403	0.84183
16	0.67506	0.92559	0.83723
17	0.66896	0.93002	0.83044
18	0.66717	0.93462	0.82845
19	0.98607	0.99091	0.99091
20	0.9719	0.97671	0.97671
21	0.96922	0.97402	0.97402
22	0.96674	0.97153	0.97153
23	0.9197	0.92966	0.94924
24	0.8947	0.92395	0.92385
25	0.88273	0.92163	0.91168
26	0.80612	0.92051	0.91651
27	0.79742	0.9499	0.90723
28	0.75882	0.93192	0.86613
29	0.73277	0.92741	0.83828
30	0.72184	0.93122	0.82657
31	0.70887	0.93024	0.81269
32	0.70614	0.92824	0.80976
33	0.70527	0.92343	0.80883

Source: Authors, (2025).

Table 6: Simulation results of DISCOs considering both DG and DSTATCOM.

Parameters	**Optimized variables, Various costs, Benefits and Profit of DISCOs**	
	PSO [11]	**GTO (Proposed)**
Optimal Location of DG and DSTATCOM	8 30	8 26
Optimal Size of the DG and DSTATCOM	1.5 MW 0.9 MVAr	1.4704 MW 0.9481 MVAr
Real Power loss (KW)	99.924	84.646
Reactive Power loss (KVAr)	62.56	60.173
Planning period	10 year	10 year
Installation cost of DG ($)	375×10^5	367.605×10^5
Installation cost of DSTATCOM($)	9×10^4	4.7404×10^4
Benefits of loss reduction ($)	4.35×10^7	4.20×10^7
Benefits of reduction in purchased($)	4.99×10^8	4.89×10^8
Operational costs of DG ($)	2.49×10^8	2.45×10^8
Maintenance cost of DG ($)	6.34×10^7	6.22×10^7
Maintenance cost of DSTATCOM ($)	1.94×10^5	4.0004×10^5
Total profit of DISCOs ($)	**1937.94×10^5**	**2187.42×10^5**

Source: Authors, (2025).

The system variables are efficiently optimized and simulation results are projected in Table 6. This table clearly explains the optimal location and sizing of DG and DSTATCOM, minimum voltage and minimum VSI and power loss.

The power loss of base case and existing PSO method is 221 KW and 99.924 KW respectively. Therefore, proposed method provides minimum power loss compared with base case and PSO method.

Table 7: Comparison of Power Loss of 33 node test system with different cases.

Case	**Technique**	**Ploss (kW)**	**%Ploss**
Base Case	--	210.98	--
Single DSTATCOM/SC	Analytical	164.60	21.98
	IA	171.81	18.57
	CSO	175.01	17.05
	MVO	151.39	28.24
	CSA	151.52	28.18
	BA	151.52	28.18
	ALOA	151.36	28.86
	GTO (Proposed)	**145.67**	**30.85**
Two DSTATCOMs/SCs	Analytical	146.64	30.50
	WIPSO-GSA	141.84	32.77
	CSA	142.07	32.66
	ALOA	141.83	32.78
	GTO (Proposed)	136.75	35.18
DG with DSTATCOM	PSO	99.924	
	FA-SCAC-PSO	93.9877	
	GTO (Proposed)	84.646	

Source: Authors, (2025).

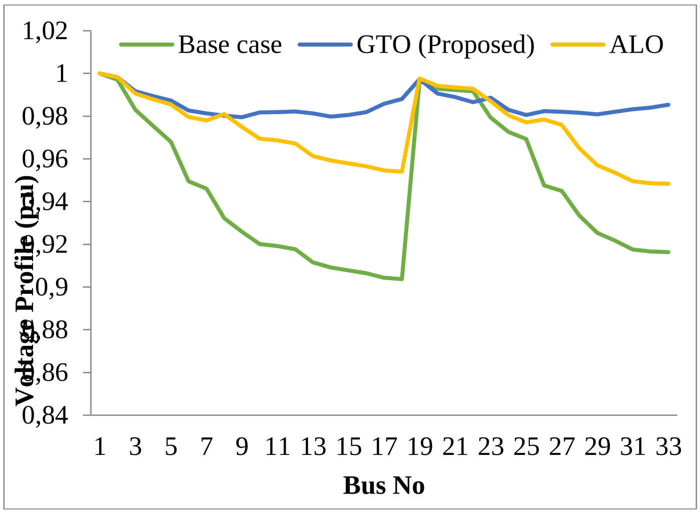

Figure 3: Comparison of Voltage profile of 33-node test system.
Source: Authors, (2025).

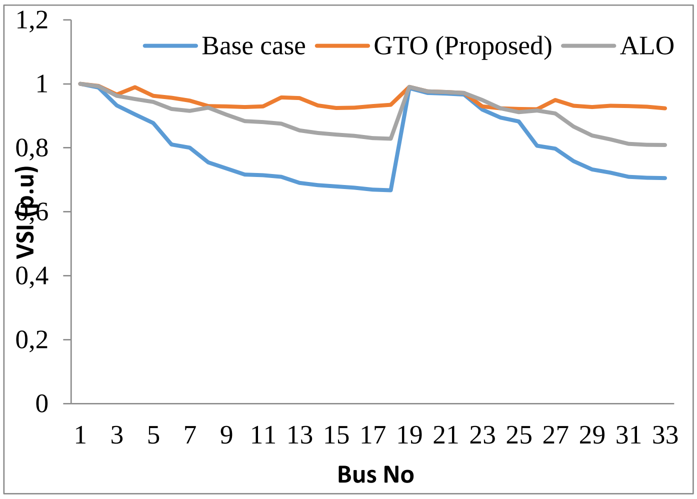

Figure 4: Comparison of VSI of 33-node test system.
Source: Authors, (2025).

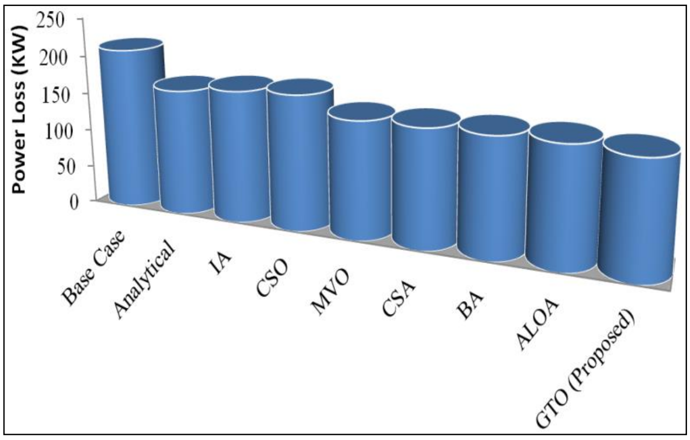

Figure 5: Comparison of Power loss Considering single DSTATCOM.
Source: Authors, (2025).

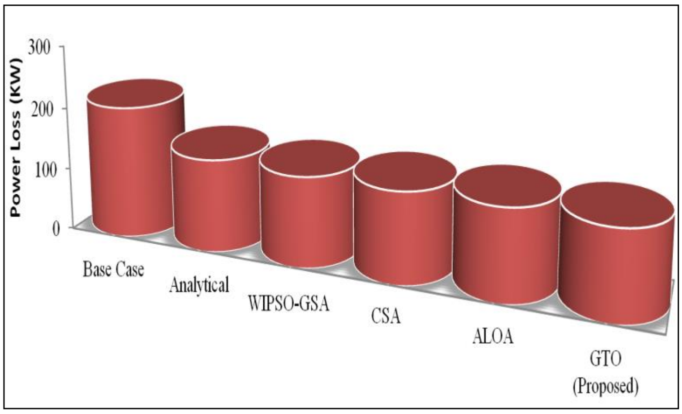

Figure 6: Comparison of Power loss Considering two DSTATCOMs.
Source: Authors, (2025).

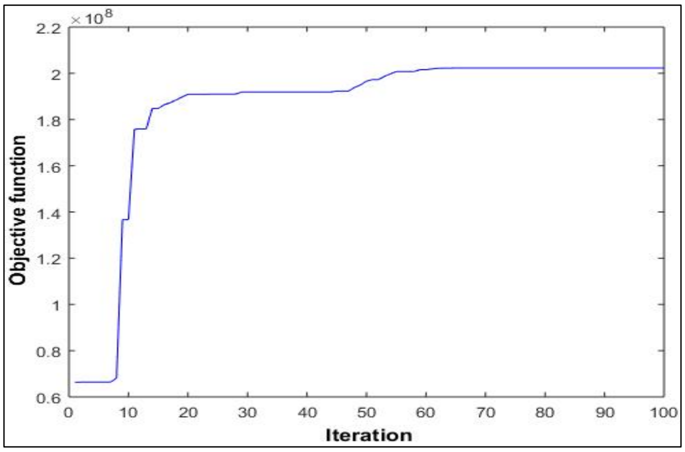

Figure 7: Convergence curve of 33-bus test system.
Source: Authors, (2025).

In the DISCOs, various cost, benefits and profit are calculated by using the GTO method. The Table 6 also explains the cost-benefit analysis of DOSCOs considering DSTATCOM with DG placement. The power loss and percentage of power loss reduction for three different cases are compared with other available methods and numerically and graphically represented in the Table 7 and Figure 5 and Figure 6. The Convergence curve of 33-bus test system is shown in Figure 7. From the Table 6, the proposed method having maximum profit, minimum power loss with less computational time compared with PSO method.

V .CONCLUSION

This paper analyzes the cost-benefit of DISCOs by optimal allocation of DG and DSTATCOM in radial distribution network. A simple and effective method of GTO algorithm has been proposed to obtain the best solution. Optimal placement of DG and DSTATCOM has been obtained using GTO to maximize the profit of DISCOs. The results of GTO are implemented for 33 node test systems. The algorithm is programmed in MATLAB software package. The outcomes such as voltage at each bus, VSI, real and reactive power loss, installation cost, operating and maintenance cost of both DG and DSTATOM, profit of DISCOs are compared with existing approaches. The results display efficacy of GTO approach for solving the voltage stability problem. The advantage of GTO is its simplicity, reliability and efficiency for practical applications.

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