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Cost-Benefit Analysis of DISCOs by Optimal Allocation of DGs and DSTATCOM using GTO Algorithm

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ABSTRACT- Electric power Distribution Companies (DISCOs) provide low-cost, reliable, and consistent voltage power from distribution substations. DISCOs have radial transmission lines with all buses as load buses and no generating buses. The voltage at each bus decreases, resulting in larger network losses and voltage variations, which lowers DISCO and customer costs and benefits. This study strategically uses Distributed Generation (DGs) and DSTATCOM to optimize cost-benefit analysis and voltage stability for Distribution Companies (DISCOs). We planned DG unit and DSTATCOM deployment using a new and comprehensive Group Teaching Optimization (GTO) method in this study. The algorithm considers Distribution Company and DG Owner profitability simultaneously. Group Teaching Optimization (GTO) is used on a 33-node test system. MATLAB simulations show the GTO's usefulness in Distribution System Operators.

Keywords: Distribution Company, DGs and DSTATCOM, Power loss minimization, Profit maximization, Group Teaching Optimization (GTO) algorithm.

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1. INTRODUCTION

DISCOs want to meet Radial Distribution Network load demand and give consumers stable power. Distribution feeders may lose energy and be unreliable because most distribution network loads are inductive [1]. Distribution system failures would substantially impact end-user electricity supply. Distribution system planners must create, develop, and manage energy-efficient, dependable distribution networks. Compensation devices optimise technical and economic benefits in the distribution network [2, 3].

Researchers' compensatory devices improved DISCO's competition environment, making it more stable and profitable. AI immune systems [4] need higher power and reduced network loss. Author DSTATCOM optimises with a cheap synthetic immune system. Biogeography Based Optimisation [5] solved it. DG units were optimised to reduce network impact. The SALP Swarm Algorithm [6] may also help. RDS hacks stabilise network loss with Alternative Energy Sources and Capacitor Units [7]. Public medium voltage distribution networks incorporate math optimisation. RDS, DG, and D-STATCOM stabilise and reduce network loss [8]. VSI and LSF placed DG and D-STATCOM values. In competition, the PSO algorithm [9] calculated DISCO costs and DG owners' RDS benefits. PSO received optimal DG and Capacitor unit values and sizes. The DG and capacitor setup, operation, and maintenance expenses were addressed. The hybrid Weight Improved Particle Swarm Optimisation with Gravitational Search approach [10] assessed DISCO cost-benefit. The projected method efficiently implements multiple DG and capacitor units compared to earlier methods. DG unit installation costs and benefits were calculated using the Elephant Herding Optimisation Algorithm [11]. Power-factor benefits analysis. Energy storage and DG units boost DISCO revenues. Optimisation optimised DG storage, location, and size [12]. Similar problems were overcome by hybrid oppositional social engineering differential evolution with Lévy flights.

Distribution System Operators (DISCOs) and Distributed Generation (DG) owners were compared using an improved Genetic Algorithm (GA) with decision-making analysis [14]. The benefits of numerous types of distributed generators (DGs) for DISCOs and DG owners were explored. DISCO profitability is increased by Moth-Flame Optimisation [15] using network reconfiguration, DGs, and Capacitors. A typical Consumer Payment Index and Local Marginal Price maximised DISCO mesh network profit [17]. We used DG units to simulate.

DISCOs profit from optimal power flow [18]. Author investigated power production and market costs. The e-constraint method to fuzzy logic [19] may maximise DISCO's revenues. For nursery answers, short-term planning, energy storage, and active network management were considered. The cost and utility of DISCO's Ant-Lion Optimisation Algorithm were assessed using single and multiple DSTATCOM [21]. DISCO profits increased after linking the DSTATCOMs. One or three DSTATCOMs on the network lowered profit due to setup and maintenance costs.

Group Teaching Optimisation (GTO), an intelligent soft computing strategy, maximises Distribution System Operators (DISCOs) dependability and cost-benefit in a competitive energy market. Integrating DSTATCOM and DG units correctly increases the proposed test system's reliability. GTO searchers can better position and size DSTATCOM/DG units. It maximises DISCO profitability within electricity market limits. IEEE33 node tests GTO validity.

2. PROBLEM FORMULATION

The GTO approach is employed to ascertain the costs and benefits of DISCOs by ensuring that both DGs and DSTATCOM relate to optimal values.

2.1. Objective Function

The main contribution of the present work is maximizing the profit of DISCOs

$$Max\ \Pr ofit = Benefits - Investments \quad (1)$$

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

$$\Pr ofit = B_1 + B_2 - \{C_1 + C_2 + C_3\} \quad (3)$$

2.2 Benefit Evaluation of DISCOs

2.2.1. Advantages of actively reducing power demand from the distribution line

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

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

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

The present worth Value factor is considered in *equation (4)* and find the real value of electricity generated from DG by the distributed company can be calculated as:

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

2.2.2. Benefits of Loss reduction

$$B_2 = \sum_{i=1}^{NDG} \sum_{j=1}^{NCap} \Delta LOSS_{ij} \times EP_G \times \Delta T \quad (7)$$

The calculation for the present worth value of loss reduction revenue in a forecasted horizon is as follows:

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

2.3 Cost evaluation of DISCOs

2.3.1. Investment cost of DG and DSTATCOM

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

2.3.2. Operating Cost of DG and DSTATCOM

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

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

2.3.3. Maintenance Cost of DG and DSTATCOM

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

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

2.4 System Constraints

2.4.1. Power balance constraints

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

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

2.4.2. Voltage limits

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

2.4.3. Current limit

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

2.4.4. Size of the DG and DSTATCOM

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

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

3. SOLUTION METHODOLOGY

3.1 Proposed GTO algorithm

The goal of the suggested Group Teaching Optimization Approach (GTOA) is to increase class knowledge and learning capacity by making group instruction a standard practice. Although it may be challenging, it is vital to recognize and adapt students' diversity when applying a group teaching technique, considering the wide range of features they exhibit. Therefore, students' learning processes must consider the aforementioned factors. References [20, 21] thoroughly explain the four phases of the GTO approach, and *figure 1* shows the GTO framework.

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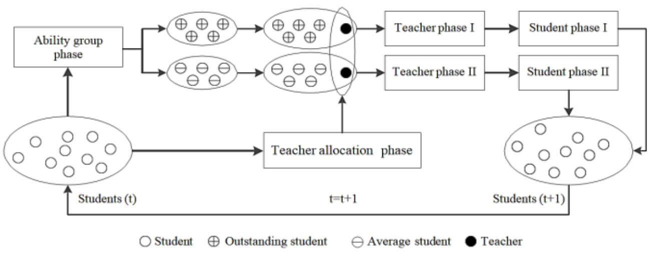

Figure 1. framework structure of the GTO algorithm

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

3.1.1 Ability grouping phase

Assuming a normal distribution, it is clear that the whole class's information is taken into account. According to the normal distribution,

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

3.1.2 Teacher phase

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

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

$$M^t = \frac{1}{N}\sum_{i=1}^{N} x_i^t \tag{22}$$

$$b + c = 1 \tag{23}$$

Teacher phase II

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

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.

$$x_{teacher,i}^{t+1} = \begin{cases} x_{teacher,i}^{t+1}, f\left(x_{teacher,i}^{t+1}\right) < f\left(x_i^t\right) \\ x_i^t, \quad f\left(x_{teacher,i}^{t+1}\right) \geq f\left(x_i^t\right) \end{cases} \tag{25}$$

3.1.3 Student phase

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

$$x_{teacher,i}^{t+1} = \begin{cases} x_{teacher,i}^{t+1} + e \times \left(x_{teacher,i}^{t+1} - x_{teacher,j}^{t+1}\right) + g \times \left(x_{teacher,i}^{t+1} - x_i^t\right), f\left(x_{teacher,i}^{t+1}\right) < f\left(x_{teacher,j}^{t+1}\right) \\ x_{teacher,i}^{t+1} - e \times \left(x_{teacher,i}^{t+1} - x_{teacher,j}^{t+1}\right) + g \times \left(x_{teacher,i}^{t+1} - x_i^t\right), f\left(x_{teacher,i}^{t+1}\right) \geq f\left(x_{teacher,j}^{t+1}\right) \end{cases} \tag{26}$$

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

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

3.1.4 Teacher allocation phase

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

$$T^t = \begin{cases} x_{first}^t, & f\left(x_{first}^t\right) \leq f\left(\frac{x_{first}^t + x_{second}^t + x_{third}^t}{3}\right) \\ \frac{x_{first}^t + x_{second}^t + x_{third}^t}{3}, & f\left(x_{first}^t\right) > f\left(\frac{x_{first}^t + x_{second}^t + x_{third}^t}{3}\right) \end{cases} \tag{28}$$

3.2 Implementation of GTO Algorithm to maximize the DISCOs profit

To determine the optimal placement and size of a combined Distributed Generation (DG) and Distribution Static Compensator (DSTATCOM) system, in order to assess the potential revenue for Distribution Companies (DISCOs) in a competitive energy market, the following stages should be followed: The proposed approach additionally considers factors such as installation, operational, and maintenance costs of the DG and DSTATCOM, as well as income generation, power loss reduction, voltage enhancement at nodes, and optimal placement and sizing of the DG and DSTATCOM in a radial distribution system.

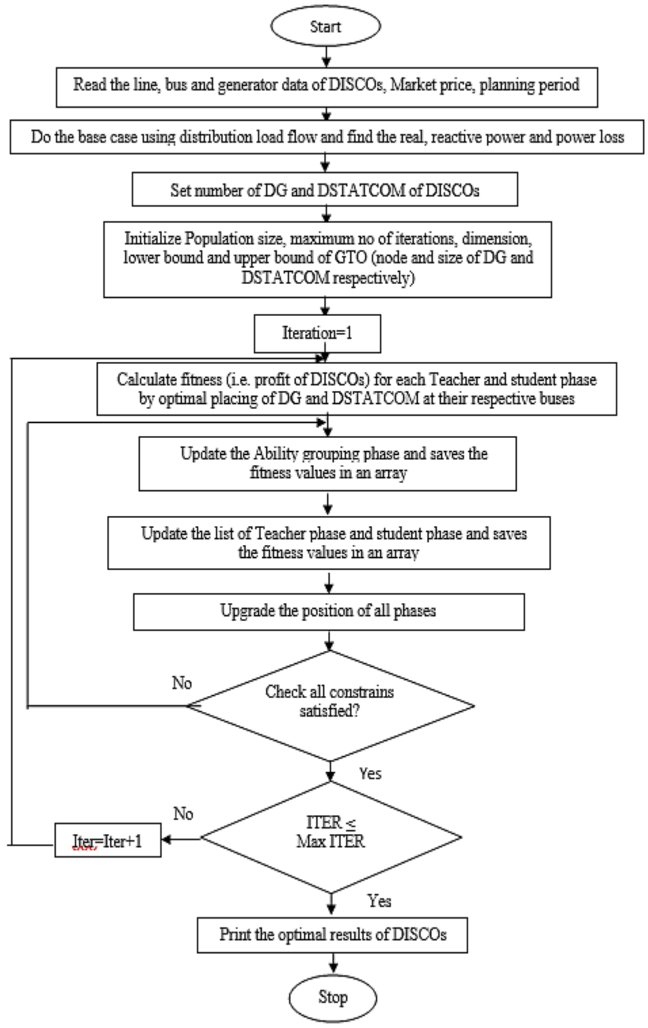

Figure 2. Flow diagram of GTO for enhancing for Profit of DISCOs

4. RESULTS AND DISCUSSION

The accuracy of the proposed GTO method is assessed by conducting tests on the IEEE-33 node test system. The method effectively optimizes system parameters to attain optimal solutions, boosting profit while avoiding network losses. The optimization procedure was performed using MATLAB version R2021a on a PC equipped with an Intel Core i3 CPU operating at a frequency of 2.10 GHz and 4GB of RAM. In the 33-node test system, the initial bus is commonly selected as the reference bus and linked to the substation (S/S). The control parameters for Gate Turn-Off Thyristor (GTO) are listed in *table 1*. *Figure 1* displays the schematic representation of the 33-node RD network in a single-line diagram. The line data, bus data, and system demand are acquired from reference [12]. The distribution load flow analysis has been employed to solve the network in each of the scenarios.

Table 1. Control parameters of GTO

Parameters	Value
Population size	50
Number of variables	10
Random number	0 to 1
Maximum number of iterations	500

The placement of DSTATCOM and DG is moving forward for a 10-year planning time. The best distribution is made to make the voltage more stable and help DISCOs make more money. The planned GTO is based on the best site and size for the DG and DSTATCOM. The suggested GTO method was used to help the DISCO make the most money possible in three different test cases, including.

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

For test *case 1*, we are considering a single DSTATCON with operating limits of 0 to 2MVAr capacity. The GTO operators (Teacher phase 1 & 2, Student phase, and Teacher allocation phase) effectively optimize the placement and value of DSTATCOM to monitor and control reactive power in the network, improving voltage profile, reducing system losses, and maximizing profits for DISCOs. The numerical results of the DISCOs' simulation, considering a single DSTATCOM, are presented in *table 2*.

Table 2. Simulation results of DISCOs considering single DSTATCOM

Parameters	Optimized variables, diverse costs, benefits, and profits of Distribution Companies (DISCOs)		
	Base Case	ALO	GTO (Proposed)
Optimal location and size of DSTATCOM in MVAr	--	30 1.258	26 1.1256
Real Power loss (kW)	210.99	151.36	145.67
Reactive Power 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

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$\times 10^6$. 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 *scenario 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 $\times 10^6$ respectively.

The minimal power loss is 35.19 percent lower than the base case figure, and the DISCO's profit is 18.1 percent higher than with the ALO approach, as shown in Table 3. Using a single DSTATCOM in the proposed distribution network improves voltage at each bus, VSI, power loss minimisation, and DISCO profitability compared to using two. Distribution businesses and the system are both benefited by correctly placing and allocating DSTATCOMs.

To increase DISCO profits, scenario 3 suggests using a single DSTATCOM in conjunction with a DG unit. It is impossible to minimise the real power loss of the system under consideration and maximise the profit of the Distribution Companies (DISCOs) without the Distributed Generation (DG) unit. Integrating the DG unit and DSTATCOM into the RDS allows

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for the injection of reactive and actual power into the network. Minimising power loss and voltage profile is done efficiently. Installation, operational, and maintenance expenses for DISCOs have increased due to the incorporation of DG units.

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
Real Power loss (kW)	210.99	141.83	136.75
Reactive Power 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

By optimising the placement and size of DG and DSTATCOM, the predicted GTO approach maximises earnings while minimising overall costs of DISCOs. With 8 MW and 26 MW, 1.4704 MVAr and 0.9481 MVAr, respectively, are the ideal dimensions and locations for the Distributed Generation (DG) and Distribution Static Synchronous Compensator (DSTATCOM). The result is a considerable improvement in voltage deviation, VSI, and voltage at each bus. You can see the voltage profile and VSI in *figures 3 and figure 4*, which compare the base case with the ALO approach. As seen in *figures 3 and figure 4*, most buses experience an improvement in voltage level and stability.

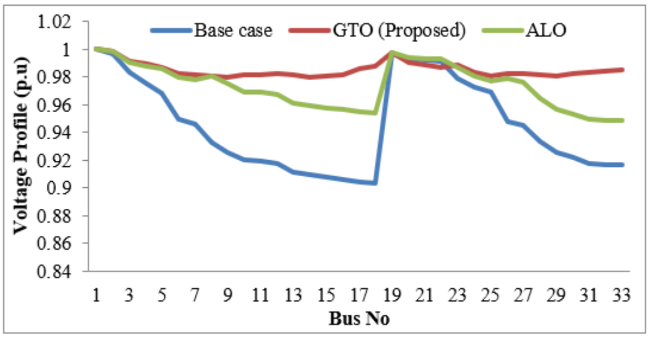

Figure 3. Comparison of Voltage profile of 33-node test system

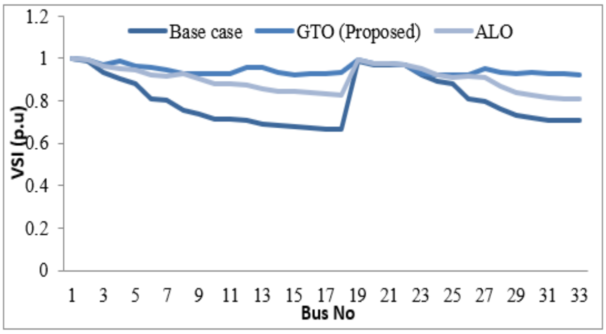

Figure 4. Comparison of VSI of 33-node test system

Table 4. Simulation results of DISCOs considering both DG and DSTATCOM

Parameters	Optimized variables, Various costs, Benefits and Profit of DISCOs	
	PSO [11]	GTO (Proposed)
Optimal placement of DG and DSTATCOM	8 30	8 26
Best value 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
Forecasted Duration	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

This chart presents a detailed analysis of the most suitable placement and dimensions of Distributed Generation (DG) and Distribution Static Synchronous Compensator (DSTATCOM), along with the minimum voltage, minimal Voltage Source Inverter (VSI), and power loss. The power loss of the base scenario is 221 KW, while the power loss of the conventional PSO approach is 99.924 KW. Therefore, the proposed strategy minimises power loss to a greater extent compared to the base case and PSO method.

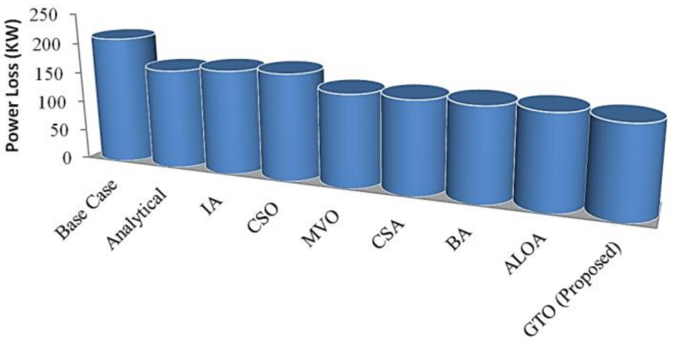

Figure 6. Comparison of Power loss Considering single DSTATCOM

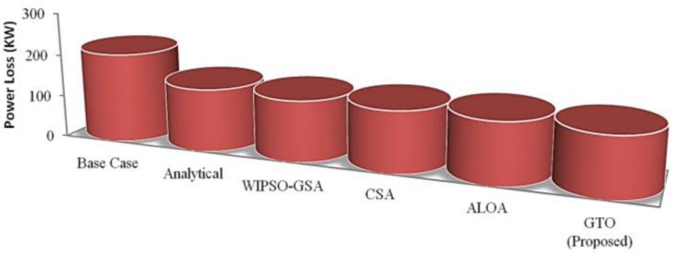

Figure 6. Comparison of Power loss Considering two DSTATCOMs

The GTO approach is used in DISCOs to calculate various costs, benefits, and profits. The power loss and the corresponding reduction percentages for three distinct scenarios are compared to other approaches and displayed graphically in *figures 5 and figure 6*. displays the Convergence curve of the 33-bus test system. According to the suggested technique demonstrates the highest profit, the lowest power loss, and requires less computational time compared to the PSO method.

5. RESULTS AND DISCUSSIONS

This paper looks at the cost-benefit of DISCOs by finding the best way to divide up DG and DSTATCOM in a radial distribution network. To get the best answer, a simple and effective GTO algorithm method has been suggested. The best places for DG and DSTATCOM to be placed have been found using GTO to help DISCOs make the most money. The results of GTO are used to build 33 node test systems. The method is written in the MATLAB programming language. Results include voltage at each bus, VSI, real and reactive power loss, installation cost, operating and upkeep costs for both DG and DSTATOM, and DISCOs' profits. These are compared to methods that have already been used. The results show that the GTO method works to fix the voltage stability issue. The good things about GTO are that it is easy to use, reliable, and effective in real-world situations.

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