INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

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OPEN ACCESS

Received: 03-05-2023

Accepted: 01-08-2023

Published: 19-09-2023

Citation: Kannemadugu RP, Adhimoorthy V, Devi AL (2023) Optimal Allocation of Combined DG and DSTATCOM for Enhancement of Voltage Stability in Radial Distribution Networks. Indian Journal of Science and Technology 16(35): 2845-2855. https://doi.org/10.17485/IJST/v16i35.1042

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Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Optimal Allocation of Combined DG and DSTATCOM for Enhancement of Voltage Stability in Radial Distribution Networks

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Abstract

Objectives: To improve the voltage profile, minimize the network power loss and enhance the stability of the Redial Distribution Systems (RDS). **Methods:** A novel and successful meta-heuristic method of Group Teaching Optimization (GTO) algorithm is proposed to evolve the solution of voltage stability in RDS. The effective compensating devices of DG and DSTATCOM are used for increasing the voltage profile and reducing the system losses. The VSI is also calculated to predetermine the best position of the two compensating devices **Findings:** GTO is effective in finding the optimal position and sizing of compensating devices. To evaluate the applicability and efficiency of GTO it's tested on standard IEEE 34 and 69 note RDS. Implementation of GTO algorithm is made using MATLAB software. The simulated results of voltage profile, VSI, Network loss, optimal sizing and position of the DG and DSTATCOM are displayed. **Novelty:** GTO is a parameter less algorithm; so it has more searching ability, provides accurate results and robustness. Obtained results are also compared with other soft computing methods such as PSO and CSA to prove the performance of the GTO method.

Keywords: Distribution Systems; Voltage Stability; DG And DSTATCOM Placement; Power Loss Minimization and GTO Algorithm

1 Introduction

In the electric power industry, Distribution systems hold a very significant position in the power system since it is the main point of connection between distribution of bulk power and consumers. Effective planning of radial distribution network is required to meet the present growing domestic, industrial and commercial load day by day. The real power loss is an important factor, because it affects the efficiency and may disturb the voltage patterns of the RDS.

Many researchers have developed various mathematical[1] and soft computing intelligent techniques[2–12] for solving voltage stability problem for minimizing network losses. Generally, fixed and switched capacitors, DG units and network reconfigurations are used to enhance the voltage stability and benefits of the costumers Whereas, a few researchers is consider the FACTS devices with meta-heuristic topology for enhancing the voltage profile of the RDS.

Recently researchers documented the various intelligent and hybrid approaches such as Teaching–Learning-Based Optimization[2], Whale Optimization[3], EP based Bat algorithm[4], An artificial fish swarm optimization algorithm[5], Hybrid ant lion optimization and multiverse optimization[6], the symbiotic organisms search and Harris hawk optimization[7], hybrid FA-SCAC-PSO algorithm[8], Cuckoo Search Algorithm[9] Equilibrium Optimizer[10], Enhanced artificial bee colony algorithm[11] and Lévy Flight Bat Algorithm[12]. All methodologies have their own advantages and disadvantages based on the accuracy and execution time.

In this research work express an establishing frame work for the main concern of voltage stability problem by placement of DG and DSTATCOM in RDS. An effective methodology of GTO algorithm is anticipated to solve this problem. To assess the proposed approach, the planning issues in the RDS have been investigated. Simulation results confirm the potential of this algorithm for identifying the minimized network losses with placement and sizing of power system components in the RDS.

2 Methodology

2.1 Objective Function

Prime objective is to minimize the system losses of the proposed RDS and mathematically defined as

$$\text{Minimize}\,(F) = \min\left(P_{T,\,\text{Loss}}\right) \tag{1}$$

The VSI of the projected problem are mathematically denoted by

$$\text{VSI}(q) = \left|V_p\right|^4 - 4\left[P_q^F \cdot X_{pq} - Q_q^F \cdot R_{pq}\right]^2 - 4\left[P_q^F \cdot R_{pq} - Q_q^F \cdot X_{pq}\right] \cdot \left|V_p\right|^2 \tag{2}$$

2.2 System Constraints

Three standard operating constraints are consider such as

- Power Balance

Power generation is equal to the power demand and power losses.

- Voltage level

$$V_{m,\,\min} \le |V_m| \le V_{m,\,\max} \tag{3}$$

- Real Power recompense

$$P_{Dm}^{\min} \le P_{Dm} \le P_{Dm}^{\max}, \quad m = 1, \ldots, N_B \tag{4}$$

- Reactive Power recompense

$$Q_{cm}^{\min} \le Q_{cm} \le Q_{cm}^{\max}, \quad m = 1, \ldots, N_B \tag{5}$$

2.3 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 criteria in students learning process. The four rules of GTO are properly reported in the reference[13–15] and structure of the GTO is shown in Figure 1.

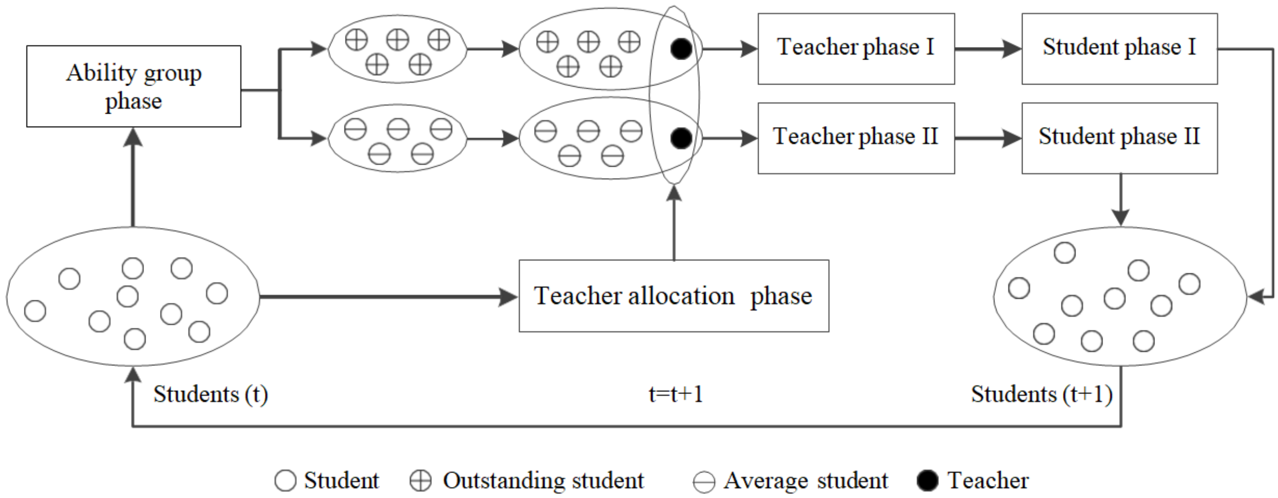

Fig 1. Framework structure of the GTO algorithm

This GTO has four phases and are mathematically represented as follows[(14)].

2.3.1 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.

$$f(x) = \frac{1}{\sqrt{2\pi\delta}} e^{\frac{-(x-u)^2}{2\delta^2}} \tag{6}$$

2.3.2 Teacher phase

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

Teacher phase I

$$x_{\text{teacher},i}^{t+1} = x_i^t + a \times \left(T^t - F \times \left(b \times M^t + c \times x_i^t\right)\right) \tag{7}$$

$$M^t = \frac{1}{N} \sum_{i=1}^{N} x_i^t \tag{8}$$

$$b + c = 1 \tag{9}$$

Teacher phase II

$$x_{\text{teacher},i}^{t+1} = x_i^t + 2 \times d \times \left(T^t - x_i^t\right) \tag{10}$$

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.

$$x_{\text{teacher},i}^{t+1} = \begin{cases} x_{\text{teacher},i}^{t+1}, & f\left(x_{\text{teacher},i}^{t+1}\right) < f\left(x_i^t\right) \\ x_i^t, & f\left(x_{\text{teacher},i}^{t+1}\right) \geq f\left(x_i^t\right) \end{cases} \tag{11}$$

2.3.3 Student phase

The student phase of the GTO is represented as

$$x_{\text{teacher},i}^{t+1} = \begin{cases} x_{\text{teacher},i}^{t+1} + e \times \left(x_{\text{teacher},i}^{t+1} - x_{\text{teacher},j}^{t+1}\right) + g \times \left(x_{\text{teacher},i}^{t+1} - x_i^t\right), f\left(x_{\text{teacher},i}^{t+1}\right) < f\left(x_{\text{teacher},j}^{t+1}\right) \\ x_{\text{teacher},i}^{t+1} - e \times \left(x_{\text{teacher},i}^{t+1} - x_{\text{teacher},j}^{t+1}\right) + g \times \left(x_{\text{teacher},i}^{t+1} - x_i^t\right), f\left(x_{\text{teacher},i}^{t+1}\right) \geq f\left(x_{\text{teacher},j}^{t+1}\right) \end{cases} \tag{12}$$

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

$$x_i^{t+1} = \begin{cases} x_{\text{teacher },i}^{t+1}, f\left(x_{\text{teacher },i}^{t+1}\right) < f\left(x_{\text{student },i}^{t+1}\right) \\ x_{\text{student },i}^{t}, f\left(x_{\text{teacher },i^t,}^{t+1}\right) \geq f\left(x_{\text{student },i}^{t+1}\right) \end{cases} \tag{13}$$

2.3.4 Teacher allocation phase

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

$$T^t = \begin{cases} x_{\text{first}}^t, & f\left(x_{\text{first}}^t\right) \leq f\left(\frac{x_{\text{first}}^t + x_{\text{second}}^t + x_{\text{third}}^t}{3}\right) \\ \frac{x_{\text{first}}^t + x_{\text{second}}^t + x_{\text{third}}^t}{3}, & f\left(x_{\text{first}}^t\right) > f\left(\frac{x_{\text{first}}^t + x_{\text{second}}^t + x_{\text{third}}^t}{3}\right) \end{cases} \tag{14}$$

2.4 Implementation of GTO Algorithm for voltage stability problem

The GTO algorithm has been used to calculate and compute the voltage stability problem by properly fitting and measuring the DC and DSTACOM using the following steps..

1. As a first step, read the system information like, line data, bus data, base MVA, base KV and rating of RDS, capacity of DG and DSTACOM.

2. Execute the load flow analysis using distribution load flow for the base case

3. Determine and fix the number of DG and DSTACOM are to be used in RDS

4. Initialize the GTO control parameters which include the maximum number of functions, population size, the limits of design variables (node number and size of the DG and DSTACOM respectively), dimension of problem and fitness functions. Population of GTO which can be mathematically represented by

$$X^t = [x_1^t, x_2^t, \ldots\ldots, x_N^t]^T = \begin{bmatrix} x_{1,1}^t & x_{1,2}^t & \cdots & x_{1,D}^t \\ x_{2,1}^t & x_{2,2}^t & \cdots & x_{2,D}^t \\ \vdots & \vdots & & \vdots \\ x_{N,1}^t & x_{N,2}^t & \cdots & x_{N,D}^t \end{bmatrix} \tag{15}$$

$$x_{i,j}^t = l_i + (u_i - l_i) \times \text{K} \tag{16}$$

5. Set iteration=1

6. Calculate fitness function of the proposed problem. I.e. loss in net work using teacher and student phase by appropriate placing of DG and DSTACOM at their respective buses. Evaluation of fitness value for the objective function is

$$\text{fitness } = \frac{1}{1 + \text{ objective function}} \tag{17}$$

7. The fitness values of individuals are calculated and the optimal solution G^t is selected. The current number of function evaluations $T_{current}$ current is updated by 17.

$$T_{\text{Current }} = T_{\text{Current }} + N \tag{18}$$

8. T current is greater than the maximum number of operation evaluations T, the algorithm ends and the optimal solution GT is outputted. Otherwise go to step 9.

9. Teacher allocation phase, the first three best individuals are selected. Then the teacher T^t is calculated.

10. Update the position of the all phases.

11. The fitness values of individuals are calculated using equation (18)

$$T_{\text{Current }} = T_{\text{Current }} + 2N + 1 \tag{19}$$

12. Compute the present position of all phases of GTO algorithm.

13. Check the all constrains and maximum number of iteration reached if yes move to next step. else go to step 6.

14. Print the obtained results and stop

The flow diagram of proposed method is displayed in Figure 2.

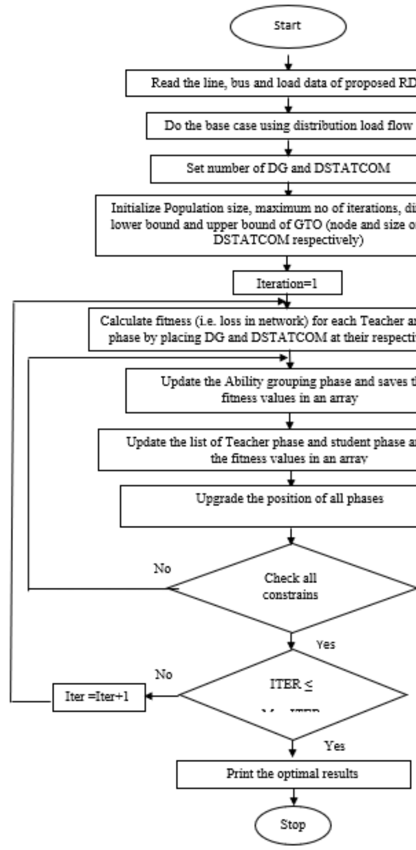

Fig 2. Flow chart of the proposed GTO technique for voltage stability problem

3 Results and Discussion

In this section, express the effectiveness of planned GTO by testing of two different 34 and 69 node RDS. This paper DG units and DSTATCOM is interconnected and inject real and reactive power to enhance the voltage profile and minimize the system losses. GTO is a parameter less algorithm so the control parameters are automatically updated and conmen parameters of population size and maximum number of iterations is only needed for achieving the best solution of the proposed test systems.

The line data and bus data of 34 node test system is adapted from reference [3] and 69 node test system taken from reference [5]. The base MVA and base KV of the 34 node is 100MVA and 11KV and 69 node is 100MVA and 12.6 KV respectively. The applied GTO algorithm is programmed using MATLAB platform.

3.1 Test system 1: 34-node system

The sing line structure of 34 node system is exposed in reference [3]. It contains 33 buses with 34 nodes and system data are taken from same reference. The terminal voltage and base case real power loss is 11KV and 221.72 KW respectively.

The Parameter of GTO is moth = 30, iterations = 100, total variables = 7. The following three different test cases are

- Case 1: Only DG units
- Case 2: Only DSTATCOM
- Case 3: both DGs and DSTATCOM.

Initially, distribution power flow method is considered to do the base case load flow study. Then GTO algorithm is applied to optimize the combined sizing and passions of the DG and DSTATCOM. The tuned best position and value of the both component is 22, 23 and 2.3278 MW, 1.371 MVAr respectively. The DG and DSTATCOM installed in the node 22 and 23 with inject real and reactive power of 2.3278 MW and 1.371 MVAr and do the load flow analysis using same distribution power flow method.

Table 1. Voltage profile for 34-node RDS with different cases

Bus No.	**Voltage Profile**			
	Base Case	**Only DG**	**Only DSTATCOM**	**DG and DSATATCOM**
1	1.0000	1.0000	1.0000	1.0000
2	0.99473	0.9965	0.99493	0.99711
3	0.99016	0.99354	0.99054	0.99472
4	0.98377	0.98989	0.98434	0.99168
5	0.9783	0.98691	0.97905	0.98924
6	0.97317	0.98428	0.97410	0.98715
7	0.96936	0.98051	0.97028	0.98339
8	0.96726	0.97843	0.96819	0.98132
9	0.9648	0.976	0.96573	0.97889
10	0.96362	0.97483	0.96455	0.97773
11	0.96316	0.97438	0.96409	0.97728
12	0.96302	0.97425	0.96396	0.97714
13	0.98982	0.99321	0.99021	0.99439
14	0.98952	0.99291	0.9899	0.99409
15	0.98944	0.99283	0.98982	0.99401
16	0.98943	0.99282	0.98981	0.994
17	0.96933	0.98341	0.97046	0.98691
18	0.96618	0.98298	0.96751	0.98706
19	0.96267	0.98303	0.9642	0.9877
20	0.9599	0.98349	0.96123	0.9887
21	0.95756	0.98437	0.95869	0.99012
22	0.95485	0.98628	0.95576	0.99259
23	0.95218	0.9837	0.95341	0.99002
24	0.94967	0.98127	0.95128	0.98761
25	0.94847	0.9801	0.95008	0.98645
26	0.9480	0.97965	0.94961	0.98601
27	**0.94160**	**0.97952**	**0.94947**	**0.98587**
28	0.96902	0.98018	0.96995	0.98306
29	0.9688	0.97996	0.96973	0.98284
30	0.96869	0.97984	0.96962	0.98273
31	0.96328	0.9745	0.96421	0.97739
32	0.96294	0.97416	0.96387	0.97706
33	0.96277	0.97399	0.9637	0.97689
34	0.96271	0.97394	0.96364	0.97684

The enhanced voltage profile for different cases such as only DG, only DSTATCOM and combined DG and DSTATCOM are shown in Table 1. In this table, case 3 (both DG and DSTATCOM) has highly improved voltage for each bus then the other two cases. The VSI of 34 node RDS with various cases are presented in Table 2. Here, VSI is effectively improved in the case 3.

The simulated results with various case studies are numerically displayed in Table 3. It includes best location, size of DG and DSTATCOM, Minimum Voltage (p.u), Voltage stability index (p.u), network losses, Total operation cost and CPU Time of the RDS with different cases. The power loss and Total operating cost of both combined DG and DSATCOM is 54.3661 MW and $ 18711.50 respectively. The convergence characteristics for both DG and DSTATCOM placement is displayed in Figure 3 from the graph, 20 iterations only nodded to achieve the best solutions. At end of the study, the obtained simulated results are compared with similar algorithms of PSA and CSA and numerical comparisons are reported in same Table 3. From the table GTO provide improved voltage profile, reduced power loss with minimum total operating cost of RDS. Therefore the projected GTO is a powerful tool for solving Complex optimization problems in the various fields of engineering science and technology.

Table 2. SI for 34-node RDS with different cases

Bus No.	**Voltage Stability Index (VSI)**			
	Base case	**Only DG**	**Only DSTATCOM**	**DG and DSATATCOM**
1	1.0000	1.0000	1.0000	1.0000
2	0.96635	0.98597	0.97892	0.98845
3	0.94851	0.97436	0.96108	0.97903
4	0.92383	0.96005	0.9364	0.96706
5	0.90324	0.94859	0.91581	0.95763
6	0.88421	0.93851	0.89678	0.94954
7	0.87028	0.92418	0.88285	0.93509
8	0.86273	0.91646	0.8753	0.92732
9	0.85385	0.90737	0.86642	0.91817
10	0.84963	0.90306	0.8622	0.91384
11	0.84801	0.9014	0.86058	0.91216
12	0.84752	0.9009	0.86009	0.91166
13	0.94734	0.97312	0.95991	0.97776
14	0.94616	0.97193	0.95873	0.97656
15	0.94584	0.97161	0.95841	0.97624
16	0.94582	0.97159	0.95839	0.97621
17	0.87018	0.93522	0.88275	0.94864
18	0.85879	0.93362	0.87136	0.94922
19	0.84618	0.93379	0.85875	0.95171
20	0.83638	0.93556	0.84895	0.95557
21	0.82815	0.93892	0.84072	0.96105
22	0.81864	0.94619	0.83121	0.97065
23	0.80939	0.93631	0.82196	0.96064
24	0.80078	0.92712	0.81335	0.95133
25	0.79668	0.92274	0.80925	0.94689
26	0.7951	0.92106	0.80767	0.94519
27	**0.78640**	**0.92056**	**0.8072**	**0.94468**
28	0.86915	0.92303	0.88172	0.93393
29	0.86834	0.9222	0.88091	0.93309
30	0.86793	0.92178	0.8805	0.93267
31	0.84843	0.90182	0.861	0.91259
32	0.84721	0.90058	0.85978	0.91134
33	0.84661	0.89996	0.85918	0.91072
34	0.84641	0.89976	0.85898	0.91051

3.2 Test system 2; 69-node system

The IEEE 69 node test system is a radial distribution system containing 69 nodes and 68 lines, which is operated at the substation bus with basic values of 100 MVA and 12.66 KV respectively. The one line diagram of 69 node RDS is consider from reference [7]. The line data bus data of this test system consider from the research by Reddy Salkuti, et al. [5].The devised GTO have more ability to achieve the global optimal solutions of 69 node RDS by two searching operators of teacher phase and student phase. The parameter setting of GTO is population size = 50, a number of variables =7, and a maximum number of iterations =500.

This test system also analysed with 3 different test cases such as DG only connected, DSRATCOM only connected and both DG and DSTATCOM has been connected to RDS. The searching operators of GTO algorithm are properly optimizes the test system parameters such as best position and sizing of both DG and DESTATCOM for enhancing the voltage profile and minimize the network losses. Optimal placement and value of DG and DESTATCOM is 61, 61 and 1.7 MW and 1.2 MVAr respectively.

Table 3. Simulation Result of 34-bus system with different test cases

Case 1: Only DG is connected			
Parameters	**PSO** [12]	**CSA** [12]	**GTO (Proposed)**
Optimal location of DG	22	23	22
Optimal size of DG (MW)	0.1996	2.3278	2.3
Minimum Voltage (p.u)	NA	0.9740	0.97438
Voltage stability index (p.u)	NA	0.8999	0.9014
Power loss (KW)	203.98	98.42	98.1375
Total operation cost ($)	NA	12032.6	11892.6
CPU Time (s)	NA	11.41	11.56
Case 2: Only DSATCOM is connected			
Optimal location of DSTATCOM	21	23	22
Optimal size of DSTATCOM (MVAr)	0.1606	1.3705	1.3703
Minimum Voltage (p.u)	NA	0.9488	0.98944
Voltage stability index (p.u)	NA	0.8105	0.8622
Power loss (KW)	212.96	175.01	175.237
Total operation cost ($)	NA	7552.5	7552.45
CPU Time (s)	NA	11.52	17.0313
Case 3: Combined DG and DSATCOM is connected			
Optimal location of DG and DSTATCOM	21 and 21	23 and 23	22 and 22
Optimal size of DG and DSTATCOM (MW and MVAr)	0.1371 and 0.1634	2.3905 and 1.3419	2.3278 and 1.371
Minimum Voltage (p.u)	0.9483	0.9771	0.97714
Voltage stability index (p.u)	NA	0.9115	0.91216
Power loss (KW)	177.10	55.03	54.3661
Total operation cost ($)	NA	18882.1	18711.5
CPU Time (s)	NA	11.69	10.63281
Base case Power loss (KW)			**221.72**
Base case Minimum Voltage (p.u)			**0.94160**
Base case Minimum Voltage stability index (p.u)			**0.7864**
Location of the Minimum Voltage			27

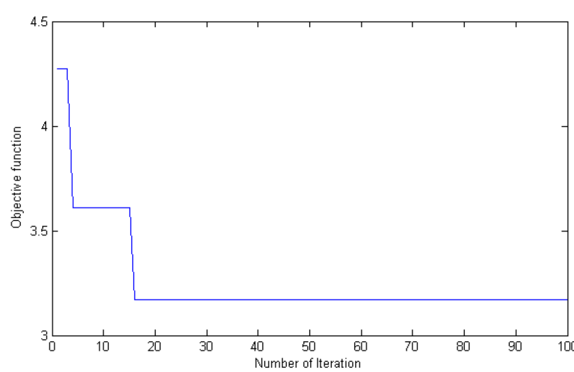

Fig 3. Convergence curve of 34 node test system (case 3)

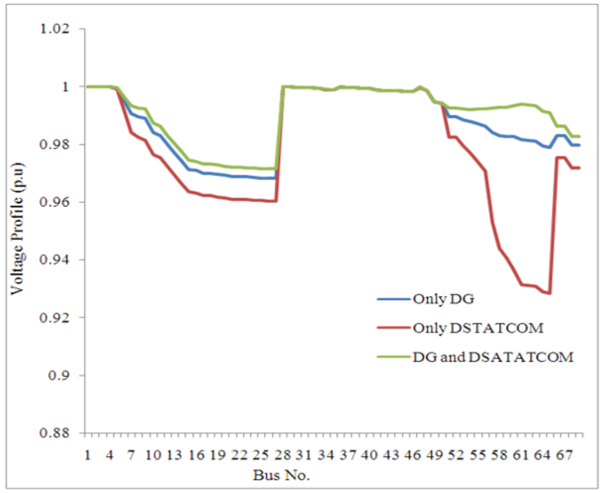

Fig 4. Voltage profile for 69-node RDS with different cases

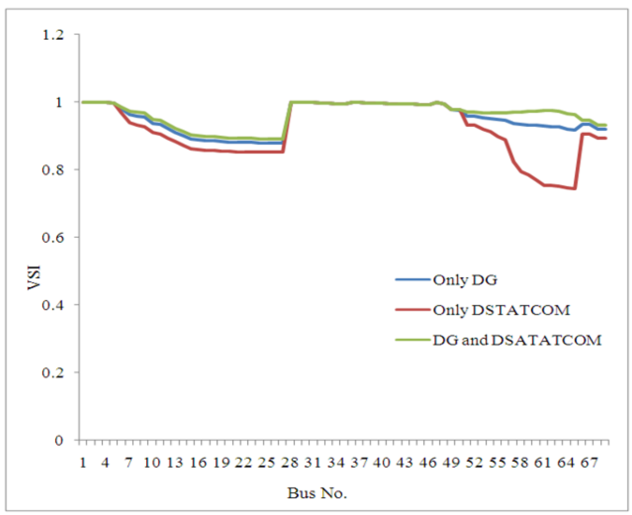

Fig 5. SI profile for 69-node RDS with different cases

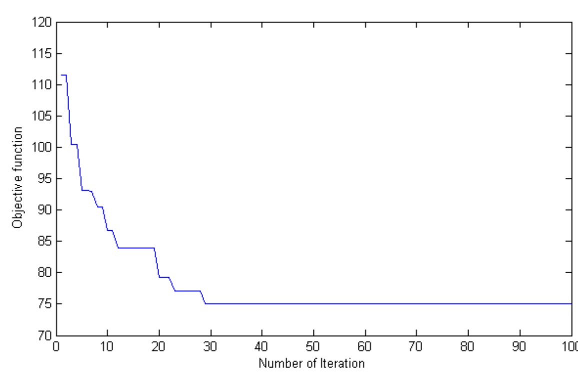

Fig 6. Convergence curve for 69 node test system (case 3)

Table 4. Simulation result of 69 node test system with different cases studies

Various test cases	Parameters	Optimal solution
Case 1:Only DG Placement	Optimal location of DG	61
	Optimal size of DG (MW)	1.87269
	Minimum Voltage (p.u)	0.96832
	Voltage stability index (p.u)	0.8801
	Power loss (KW)	83.2211
	Total operation cost ($)	9696.32
	CPU Time (s)	79.7135
Case 2 :Only DSATCOM Placement	Optimal location of DSTATCOM	61
	Optimal size of DSTATCOM (MVAr)	1.18
	Minimum Voltage (p.u)	0.96052
	Voltage stability index (p.u)	0.96052
	Power loss (KW)	152.931
	Total operation cost ($)	6511.72
	CPU Time (s)	85.599
Case 3 :Both DG and DSTATCOM Placement	Optimal location of DG and DSTATCOM	61 61
	Optimal size of DG and DSTATCOM (MW and MVAr)	1.7 1.2
	Minimum Voltage (p.u)	0.97143
	Voltage stability index (p.u)	0.89053
	Power loss (KW)	24.0689
	Total operation cost ($)	14596.3
	CPU Time (s)	23.9141
Base case Power loss (KW)		224.97
Base case Minimum Voltage (p.u)		0.9416
Base case Minimum Voltage stability index (p.u)		0.6833
Location of the Minimum Voltage		42

The improved voltage profile and VSI for three different test cases are graphically displayed in Figures 4 and 5 . From the graph, test case 3 (both DG and DESTATCOM) provide maximum enhanced voltage profile and VSI when compared with case 1 and case 2. The simulation results of 69 node test system with different case studies are tabulated in Table 4 . The minimum voltage and voltage stability index is 0.97143 (p.u) and 0.89053 (p.u) respectively. The obtained power loss and total operating cost of the 69 node test system is 24.0689 KW and $ 14596.3 respectively. The Convergence curve for combined DG with DSTATCOM placement for 69 node test system is displayed in Figure 6 . From the graph 40 iterations is only needed for achieving the optimal solutions of proposed GTO approach. Table 4 clearly explains the combined installations of both DG and DSTATCOM outputs the improved voltage profile, minimized network losses with computational time then the other two cases.

4 Conclusion

In this article, an intelligent new computational GTO technique is applied for solution of voltage stability problem by proper fitting and sizing of DG and DSTATCOM in regulated power system. The special future of GTO is a parameter free algorithm and contains various searching operators (Various phases). Therefore, effectively optimizes the system variables and getting accurate solutions with minimum computational time period. Here, GTO easily identify the best location and optimal values of DG and DSTATCOM in RDS. Case study with IEEE 34 and 69 node test system has been considered to illustrate the ability of the proposed GTO. The simulated results are numerically and graphically compared with other evolutionary approaches PSO and CSA to prove the performance of the GTO approach.

References

1) Nawaz S, Sharma M, A T. A new approach for power loss minimization in radial distribution networks. 2019. Available from: https://doi.org/10.1007/978-981-13-1822-1_1.
2) Quadri IA, Bhowmick S, Joshi D. A hybrid teaching–learning-based optimization technique for optimal DG sizing and placement in radial distribution systems. *Soft Computing*. 2019;23(20):9899–9917. Available from: https://doi.org/10.1007/s00500-018-3544-8.
3) Yuvaraj T, Devabalaji KR, Thanikanti SB. Simultaneous Allocation of DG and DSTATCOM Using Whale Optimization Algorithm. *Iranian Journal of Science and Technology, Transactions of Electrical Engineering*. 2020;44(2):879–896. Available from: https://doi.org/10.1007/s40998-019-00272-w.
4) Salkuti SR. Optimal Allocation of DG and D-STATCOM in a Distribution System using Evolutionary based Bat Algorithm. *International Journal of Advanced Computer Science and Applications*. 2021;12(4):360–365. Available from: https://doi.org/10.14569/IJACSA.2021.0120445.
5) Salkuti SUR. Optimal location and sizing of DG and D-STATCOM in distribution networks. *Indonesian Journal of Electrical Engineering and Computer Science*. 2019;16(3):1107. Available from: http://doi.org/10.11591/ijeecs.v16.i3.pp1107-1114.
6) Sultan MS, Kazmi SAA, Altamimi A, Khan ZA, Shin DR. Multi-Objective Optimization-Based Approach for Optimal Allocation of Distributed Generation Considering Techno-Economic and Environmental Indices. *Sustainability*. 2023;15(5):4306. Available from: https://doi.org/10.3390/su15054306.
7) Dash SK, Mishra S, Abdelaziz AY, Hong J, Geem ZW. Optimal Planning of Multitype DGs and D-STATCOMs in Power Distribution Network Using an Efficient Parameter Free Metaheuristic Algorithm. *Energies*. 2022;15(9):3433–3433.
8) Zellagui M, Lasmari A, Settoul S, El-sehiemy RA, El-bayeh CZ, Chenni R. Simultaneous allocation of photovoltaic DG and DSTATCOM for techno-economic and environmental benefits in electrical distribution systems at different loading conditions using novel hybrid optimization algorithms. *International Transactions on Electrical Energy Systems*. 2021;31(8):129–142. Available from: https://doi.org/10.1002/2050-7038.12992.
9) Chowdhury A, Roy R, Mandal KK. Optimal allocation of wind based DG for enhancement of technical, economic & social benefits using Cuckoo Search Algorithm for radial distribution networks. In: 2020 International Conference on Computer, Electrical & Communication Engineering (ICCECE). IEEE. 2020. Available from: https://doi.org/10.1109/ICCECE48148.2020.9223085.
10) Shaik MA, Mareddy PL, Visali N. Enhancement of Voltage Profile in the Distribution system by Reconfiguring with DG placement using Equilibrium Optimizer. *Alexandria Engineering Journal*. 2022;61(5):4081–4093. Available from: https://doi.org/10.1016/j.aej.2021.09.063.
11) Kandasamy M, Thangavel R, Arumugam T, Kumaravel S, Aruchamy S, Kim WWW, et al. Strategic incorporation of DSTATCOM and distributed generations in balanced and unbalanced radial power distribution networks considering time varying loads. *Energy Reports*. 2023;9:4345–4359. Available from: https://doi.org/10.1016/j.egyr.2023.03.076.
12) Reddy GH, Koundinya AN, Gope S, Raju M, Singh KM. Optimal Sizing and Allocation of DG and FACTS Device in the Distribution System using Fractional Lévy Flight Bat Algorithm. *IFAC-Papers On Line*. 2022;55(1):168–173. Available from: https://doi.org/10.1016/j.ifacol.2022.04.028.
13) Zhu S, Wu Q, Jiang Y, Xing W. A novel multi-objective group teaching optimization algorithm and its application to engineering design. *Computers & Industrial Engineering*. 2021;155:107198. Available from: https://doi.org/10.1016/j.cie.2021.107198.
14) Zhang Z, Jin Y. Group teaching optimization algorithm: A novel metaheuristic method for solving global optimization problems. *Expert Systems with Applications*. 2020;148:113–126. Available from: https://doi.org/10.1016/j.eswa.2020.113246.
15) U R, S M. Enhanced sine-cosine algorithm for optimal planning of distribution network by incorporating network reconfiguration and distributed generation. *Arabian Journal for Science and Engineering*. 2021;46(2):1029–1051. Available from: https://doi.org/10.1007/s13369-020-04808-9.