Journal of Harbin Engineering University
ISSN: 1006-7043
Vol 44 No. 8
August 2023

Multi objective Optimization for Enhancement of Technical-economic and Environmental Benefits of Radial Distribution Networks using GTO algorithm

Ram Prasad Kannemadugu, V. Adhimoorthy and A. Lakshmi Devi

Research Scholar, Department of Electrical Engineering, Annamalai University, Annamalai Nagar, Tamil Nadu, India.
Associate Professor, Department of Electrical and Electronics Engineering, Government college of Engineering, Bargur, Tamil Nadu, India.
Professor, Department of Electrical and Electronics Engineering, S V University College of Engineering, Sri Venkateswara University, Tirupati, India.

Abstract- In a Modern electric distribution utility structure, create a new opportunities and technological innovations for development of existing Radial Distribution System (RDS). Integration of DG based on PV panel and DSTATCOM with RDS provides more benefits interims of technically, economically and environment point of view. From the background, this paper maximizes the technical, economical and environmental benefit of RDS by proper sitting and sizing of DG and DSTATCOM in a combined manner. The benefits such as are Active Power Loss Level (APLL), Short Circuit Level (SCL), Voltage Deviation Level (VDL), Net Saving Level (NSL), and Environmental Pollution Reduction Level (EPRL).are taken in account. This problem consider as a Multi-Objective Optimization Problem (MOP) and solved by an innovative best metta-heuristic approach of Group Teaching Optimization (GTO) algorithm. The GTO effectively identify the optimal location and required value of DG and DSTATCOM by various phases of GTO..This paper also improves the voltage profile and reduces the network losses in RDS. Case study with IEEE 33 system is consider and simulated results are tabulated. The output results are compared with other similar approaches and reported in literature.

Keywords- Distribution systems, Benefits of RDS, voltage stability, DG and DSTATCOM placement, Power loss minimization and Group Teaching Optimization algorithm.

.

1 Introduction

Nowadays, deregulation of electric energy market, distribution network needs precise planning and an appropriate approach to meet the massive growth of power demand and maintain dependable electricity it provides to the consumers. The installation of additional substations or extensions of the existing network is not practically possible due to various realistic limitations. Moreover, generally distribution systems are either radial or weakly meshed in structure and have a very large R/X ratio [1], which results in poor voltage profile and higher line losses. And also, during the power generation from fossils fuel-based power stations, an enormous quantity of pollutant gases is emitted into the atmosphere, which is the main reason for the global warming. Considering these problems, the alternative technologies such as renewable energy sources (RESs) or distributed static compensator (DSTATCOM) become an immediate choice for enhancing the performances of the system. The presence of these devices in a network can result in voltage enhancement, line losses reduction, and a significant economic and environmental benefit.

Various approaches are developed to maximize the techno-economic benefits of RDS. Optimal placement off DG units in a RDS can reduce the power losses and improve the voltage profile of the distribution network by an opposition-based tuned-chaotic differential evolution [1], Multi-Objective Whale Optimization Algorithm [2], Ant Lion Optimization [3] has been applied for enhancing the techno-economic environmental benefits. Modified Shuffled Frog Leaping Algorithm [4], Wind driven optimization [5] and PSO technique with adaptive inertia weight [6] haze been used to determine the optimal sizing and placement of DGs and DSTATCOM in RDS. to maximize technical, economic, and environmental benefits.

Integration of Various DG’s such as diesel generator, solar photo-voltaic (PV) and wind generator to solve the optimization problem by optimal placing of DGs based on economic, environmental and reliability indices [7]. Improves system voltage, reduce line losses, maximise economic benefit, and decrease pollutants’ emission by the optimal allocation of renewable energy sources and distributed static compensators in a practical distribution network (PDN) by applying the Improved Crow Search Algorithm [8]. Adaptive Particle Swarm Optimization and hybrid Grey Wolf-Particle Swarm Optimization [9] approaches was used to reduce power losses, Improve the voltage profile and system reliability by DGs), consisting of solar DG and DSTATCOM with Network Reconfiguration.

Metaphor-less based the Artificial intelligence [10] approach is used to minimize the power losses, enhance the voltage profile, and voltage stability index of the RDS considering the net economic cost-benefit by network reconfiguration and integration of DGs, and Distribution Static Compensator (DSTATCOM) units placed in optimal position by applying Rao-1 method[5] and Gravitational Search Algorithm [11]. Manta Ray Foraging Optimization [12] and Multi-Objective Salp Swarm Algorithm [13].has been used to determine the Real Power Loss Level, the Short Circuit Level), the Voltage Deviation Level), the Net Saving Level (NSL), and the Environmental Pollution Reduction Level. By optimal allocation of distributed static-compensator and wind turbine type distributed generation in the DN to solve the optimum deployment problem for enhancing the voltage profile, reducing loss, maximizing the economic benefit, and decreasing the level of pollution using the rooted tree optimization technique [14]

This article, addresses the problem of establishing a conceptual frame work using an innovative intelligent tool of GTO) algorithm for Multi objective Optimization for enhancement of Technical-economic and environmental benefits in Redial Distribution Networks

- Section 2 provides the mathematical formulation of multi objective optimization problem. It includes modelling of distribution line, Objective functions, and Equality and inequality constraints.
- Section 3 proposes the solution methodology and it includes overview of GTO approach and implementation of GTO algorithm for optimal allocation and sizing of DG and DSTATCOM.
- Section 4 gives the numerical example of standard IEE-33 node test system and simulation results with different cases,
- Section 5 outlines the conclusions of the paper..

2. Mathematical Problem Formulations of Allocation

2.1 Modeling of distribution line

The EDS includes series branches, which denote the distribution lines, balanced power nodes, and constant loads. The single line diagram with DG and DSTATCOM is represented in Figure 1.

$$P_j = P_i - P_{Dj} - R_{ij}\frac{P_i^2+Q_i^2}{V_i^2} - P_{DG} \quad (1)$$

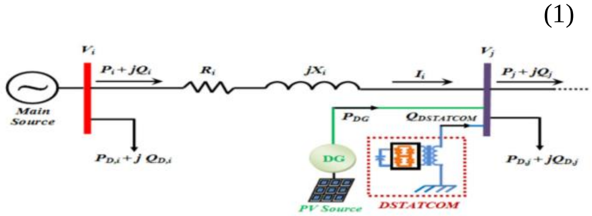


Fig.1 Single line diagram with DG and DSTATCOM

$$Q_j = Q_i - Q_{Dj} - X_{ij}\frac{P_i^2+Q_i^2}{V_i^2} + Q_{DSTATCOM} \quad (2)$$

2.2 Objective functions

In this paper, the proposed new MOF aims to solve the problem of finding the optimal size and location of DG and/or DSTATCOM units, through the maximization of APL, NSL, SCL, VDL, and EPRL, which can formulate as follows:

In this paper, α1 is taken as 0.30, while each of α2, α3, and α4 is taken as 0.20. The value of α5 is equal to 0.10. The values of these factors are based on practical indicators. The various levels applied in this paper can be expressed as follows:

$$MOF = Max \sum_{i=1}^{N_{Bus}} \sum_{j=2}^{N_{Bus}} \left(\alpha_1 . APLL_{i,j} + \alpha_2 . VDL_j + \alpha_3 . SCL_{i,j} + \alpha_4 . NSL_{i,j} . \alpha_5 . EPRL_G \right) \quad (3)$$

$$APLL = \frac{P_{LOSS}^{BeforeDG/DSTATCOM}}{P_{LOSS}^{BeforeDG/DSTATCOM} + P_{LOSS}^{AfterDG/DSTATCOM}} \times 100 \quad (4)$$

$$VDL = \frac{VD_{BeforeDG/DSTATCOM}}{VD_{BeforeDG/DSTATCOM} + VD_{AfterDG/DSTATCOM}} \times 100 \quad (5)$$

$$SCL = \frac{SC_{AfterDG/DSTATCOM} - SC_{BeforeDG/DSTATCOM}}{SC_{BeforeDG/DSTATCOM}} \times 100 \quad (6)$$

$$NSL = \frac{C_{BeforeDG/DSTATCOM} - C_{AfterDG/DSTATCOM}}{C_{BeforeDG/DSTATCOM}} \times 100 \quad (7)$$

$$EPRL = \frac{PE_{AfterDG/DSTATCOM}}{PE_{BeforeDG/DSTATCOM} + PE_{AfterDG/DSTATCOM}} \times 100 \quad (8)$$

where, the branch power loss (PLoss) can represent by:

$$P_{LOSS} = R_{ij}\frac{\left(P_{ij}^2+Q_{ij}^2\right)}{V_i^2} \quad (9)$$

Second, the voltage Deviation (VD) is as:

$$VD = \left|1 - V_j\right| \quad (10)$$

The third term is the short circuit (SC) can be defined as:

$$SC = \frac{V_j^C}{Z_{ij}} \quad (11)$$

Then, the annual losses cost (C), which is depending on P_{Loss} can be calculated as:

$$C = P_{LOSS} \times K_P \times T \quad (12)$$

Another advantage of the DG is the positive impact on the reduction of the pollutant emission, where the incorporation of DG contributes to reducing the energy produced by the sub-station, it means reducing the percentage of pollutants because the pollutants emitted from DG are null, where the number of emissions (PE) is given by the equation below60:

$$P = EG_g . AE_g \quad (13)$$

where, EGg is the amount of energy produced by the generator (noted that this amount is different depending on the size of

DG), and AEg is the amount of the types of conventional pollutants such as (CO_2, SO_2, etc.).

2.3 Equality constraints

The power balance equations are used to describe equality constraints:

$$P_G + P_{DG} = P_D + P_{LOSS} \quad (14)$$

$$Q_G + Q_{STATCOM} = Q_D + Q_{LOSS} \quad (15)$$

2.4 Inequality constraints of distribution line

$$Bus\ Voltage : V_{min} \le |V_i| \le V_{max} \quad (16)$$

$$Voltage\ drop\ limitation : |V_1 - V_j| \le \Delta V_{max} \quad (17)$$

$$Line\ Capacity : |S_{ij}| \le |S_{max}| \quad (18)$$

2.5 Inequality constraints of DG units

The limitations of the DG unit are represented by inequality constraints, which may be written as:

$$P_{DG}^{min} \le P_{DG} \le P_{DG}^{max} \quad (19)$$

$$\sum_{i=1}^{N_{DG}} P_{DG}(i) \le \sum_{i=1}^{N_{bus}} P_D(i) \quad (20)$$

$$2 \le DG_{Position} \le N_{Bus} \quad (21)$$

$$N_{DG} \le N_{DG.max} \quad (22)$$

$$n_{DG,i}/Location \le 1 \quad (23)$$

2.6 Inequality constraints of DSTATCOM units

The DSTATCOM unit's limitations are represented by inequality constraints, which may be expressed as:

$$Q_{DSTATCOM}^{min} \le Q_{DSTATCOM} \le Q_{DSTATCOM}^{max} \quad (24)$$

$$\sum_{i=1}^{N_{DST}} Q_{STATCOM}(i) \le \sum_{i=1}^{N_{bus}} Q_D(i) \quad (25)$$

$$2 \le DSTATCOM_{Position} \le N_{Bus} \quad (26)$$

$$N_{DSTATCOM} \le N_{DSTATCOM.max} \quad (27)$$

$$n_{STATCOM,i}/Location \le 1 \quad (28)$$

3. Group Teaching Optimization (GTO) Algorithm

3.1 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 criteria in students learning process..The four rules of GTO are properly reported in the reference [15] and structure of the GTO is shown in fig. 2..

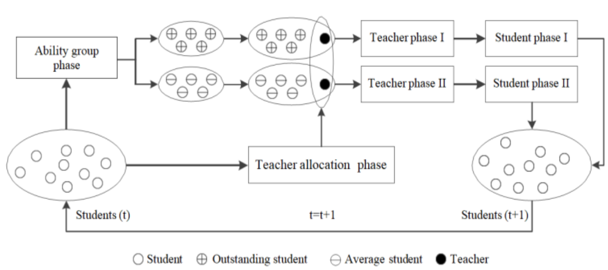


Fig.2. framework structure of the GTO algorithm

This GTO has four phases and are mathematically represented as follows [16].

3.2 Mathematical formulation of GTO algorithm

3.3.1 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.

$$f(x) = \frac{1}{\sqrt{2\pi\delta}} e^{\frac{-(x-u)^2}{2\delta^2}} \quad (29)$$

3.3.2 Teacher phase

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

Teacher phase I

$$x_{teacher,i}^{t+1} = x_i^t + a \times \left(T^t - F \times \left(b \times M^t + c \times x_i^t\right)\right) \quad (30)$$

$$M^t = \frac{1}{N}\sum_{i=1}^{N} x_i^t \quad (31)$$

$$b + c = 1 \quad (32)$$

Teacher phase II

$$x_{teacher,i}^{t+1} = x_i^t + 2 \times d \times \left(T^t - x_i^t\right) \quad (33)$$

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.

$$x_{teacher,i}^{t+1} = \begin{cases} x_{teacher,i}^{t+1}, & f\left(x_{teacher,i}^{t+1}\right) < f\left(x_i^t\right) \\ x_i^t, & f\left(x_{teacher,i}^{t+1}\right) \ge f\left(x_i^t\right) \end{cases} \quad (34)$$

3.3.3 Student phase

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

$$x_{teacher,i}^{t+1} = \begin{cases} x_{teacher,i}^{t+1} + e \times \left(x_{teacher,i}^{t+1} - x_{teacher,j}^{t+1}\right) + g \times \left(x_{teacher,i}^{t+1} - x_i^t\right), & f\left(x_{teacher,i}^{t+1}\right) < f\left(x_{teacher,j}^{t+1}\right) \\ x_{teacher,i}^{t+1} - e \times \left(x_{teacher,i}^{t+1} - x_{teacher,j}^{t+1}\right) + g \times \left(x_{teacher,i}^{t+1} - x_i^t\right), & f\left(x_{teacher,i}^{t+1}\right) \ge f\left(x_{teacher,j}^{t+1}\right) \end{cases} \quad (35)$$

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

$$x_i^{t+1} = \begin{cases} x_{teacher,i}^{t+1}, & f\left(x_{teacher,i}^{t+1}\right) < f\left(x_{student,i}^{t+1}\right) \\ x_{student,i}^{t}, & f\left(x_{teacher,i}^{t+1}\right) \ge f\left(x_{student,i}^{t+1}\right) \end{cases} \quad (36)$$

3.3.4 Teacher allocation phase

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

$$T^t = \begin{cases} x_{first}^t, & f\left(x_{first}^t\right) \le f\left(\frac{x_{first}^t + x_{second}^t + x_{third}^t}{3}\right) \\ \frac{x_{first}^t + x_{second}^t + x_{third}^t}{3}, & f\left(x_{first}^t\right) > f\left(\frac{x_{first}^t + x_{second}^t + x_{third}^t}{3}\right) \end{cases} \quad (37)$$

3.3 Implementation of GTO Algorithm for enhancement of techno-economic environmental benefits of RDS

The following steps are used to evaluate techno-economic environmental benefits of proposed test system using multi objective GTO algorithm. The proposed approach also does the various processes such as the power loss minimization, node voltage enhancement, optimal location and sizing of DGs and DSTATCOM in radial distribution system.

1. As a first step, read the system information like, line data, bus data, base MVA, base KV and rating of RDS, upper and lower limits 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 multi objective 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

$$X^t = \left[x_1^t, x_2^t, \ldots\ldots., x_N^t\right]^T = \begin{bmatrix} x_{1,1}^t & x_{1,2}^t & \cdots & x_{1,D}^t \\ x_{2,1}^t & x_{2,2}^t & \cdots & x_{2,D}^t \\ \vdots & \vdots & & \vdots \\ x_{N,1}^t & x_{N,2}^t & \cdots & x_{N,D}^t \end{bmatrix} \quad (38)$$

$$x_{i,j}^t = l_i + \left(u_i - l_i\right) \times \mathrm{K} \quad (39)$$

5. Set iteration=1.
6. Calculate fitness function of the proposed problem. i.e techno-economic environmental benefits of proposed network using various teacher and student phase by appropriate placing of DG and DSTACOM at their respective buses. fitness function can be mathematically represent as follows.

$$fitness = \frac{1}{1 + objective\ \ function} \quad (40)$$

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

$$T_{Current} = T_{Current} + N \quad (41)$$

8. If the current figure of operation assessment $T_{current}$ current is greater than the maximum number of operation evaluations T_{max}, 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 $\boldsymbol{T^t}$ is calculated.
10. Update the position of the all phases.
11 The fitness values of individuals are calculated using equation (42).

$$T_{Current} = T_{Current} + 2N + 1 \quad (42)$$

12 Compute the present position of all phases of multi objective 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

4. Results and Discussions

The dominance of the proposed multi objective GTO (MOGTO) algorithm is examined for various distribution systems. The proposed approach has been implemented on the 33-node radial distribution system consisting of base values used are 100 MVA and 12.66 KV. This test system consists of one main feeder and three laterals of the network. The total real and reactive power loads of the system are 3715 KW and 2300 KVAr, respectively. The one line diagram of 33- node test system is shown in fig. 3. This paper 3 DG units and 3 DSTATCOM is conceded to enhance the voltage profile, reduces power losses and improve the Technical-economic and Environmental Benefits of RDS

The applied GTO method is effectively tinning the optimal location of the DG and DSTATCOM for improving the Technical-economic and Environmental Benefits of RDS, The control Parameter of GTO is moth = 40, iterations = 200, total variables = 10. The projected GTO analyzed with following four different test cases such as

- Case 1. Without DG or DSTATCOM (Base case)
- Case 1: Only DG units
- Case 2: Only DSTATCOM
- Case 3: both DGs and DSTATCOM.

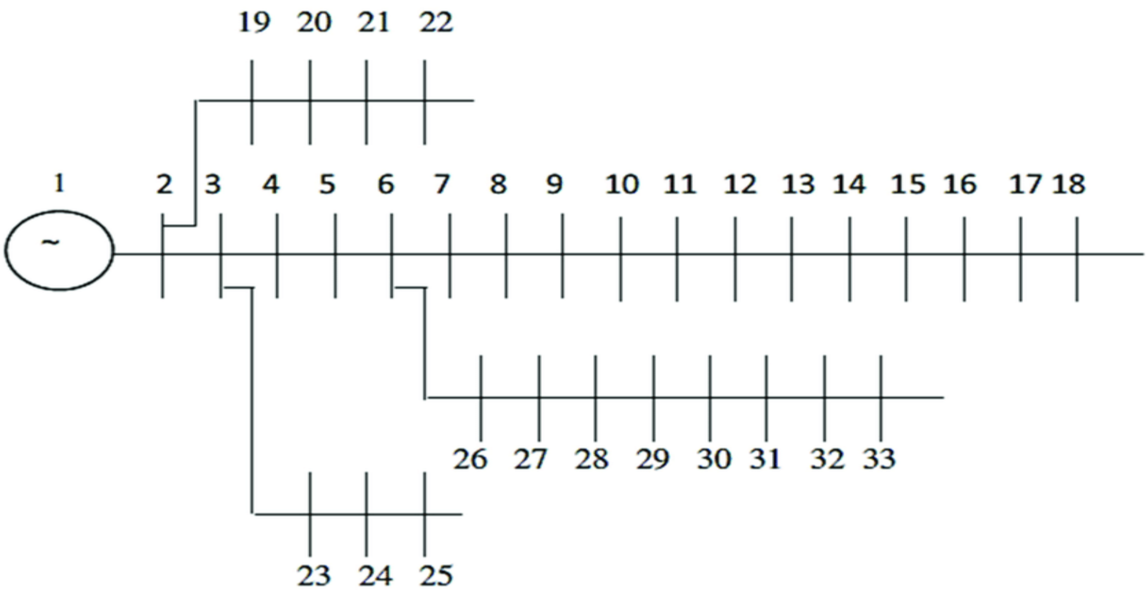


Fig. 3 Single line diagram of 33-node radial distribution system

Table 1 Voltage profile for 33-node RDS with different cases

Bus No.	Base Case	Only DG	Only DSTATCOM	Both DG and DSTATCOM
1	1.0000	1	1	1
2	0.9970	0.99879	0.99773	0.99906
3	0.9829	0.99408	0.98735	0.9958
4	0.9754	0.99192	0.98196	0.99633
5	0.9680	0.99007	0.97675	0.9969
6	0.9495	0.98376	0.9662	0.99854
7	0.9460	0.98172	0.96497	0.99847
8	0.9323	0.98063	0.9561	0.99969
9	0.9260	0.98178	0.95262	1.0022
10	0.9201	0.98347	0.94962	1.0052
11	0.9192	0.98402	0.94901	1.0055
12	0.9177	0.98518	0.94755	1.0062
13	0.9115	0.97944	0.94157	1.0005
14	0.9092	0.97731	0.93935	0.99845
15	0.9078	0.97598	0.93797	0.99715
16	0.9064	0.9747	0.93664	0.9959
17	0.9043	0.97279	0.93465	0.99403
18	**0.9037**	**0.97222**	**0.93406**	**0.99348**
19	0.9965	0.99826	0.9972	0.99853
20	0.9929	0.99469	0.99362	0.99496
21	0.9922	0.99398	0.99292	0.99426
22	0.9916	0.99335	0.99228	0.99362

23	0.9793	0.99256	0.98487	0.99226
24	0.9726	0.98998	0.98076	0.98568
25	0.9693	0.99068	0.97747	0.9824
26	0.9475	0.98333	0.96505	0.99924
27	0.9450	0.98285	0.96359	0.99894
28	0.9335	0.97931	0.95909	0.99842
29	0.9253	0.97711	0.9561	0.99842
30	0.9217	0.97728	0.95449	0.99883
31	0.9176	0.97336	0.95048	0.99914
32	0.9167	0.9725	0.94959	0.9983
33	0.9164	0.97223	0.94932	0.99804

Table 2 VSI for 33-node RDS with different cases

Bus No.	Base Case	Only DG	Only DSTATCOM	Both DG and DSTATCOM
1	1.0000	1	1	1
2	0.988107	0.99514	0.9909	0.99624
3	0.932129	0.9762	0.94952	0.98325
4	0.904787	0.96797	0.92955	0.98538
5	0.877547	0.96076	0.90998	0.98764
6	0.810823	0.93599	0.87027	0.99414
7	0.800586	0.92884	0.86695	0.99389
8	0.754449	0.92451	0.83478	0.99875
9	0.734943	0.92898	0.82335	1.0087
10	0.716499	0.9354	0.81302	1.0207
11	0.713974	0.93758	0.81112	1.022
12	0.709272	0.94202	0.80611	1.0249
13	0.690181	0.92005	0.78577	1.0019
14	0.683439	0.91224	0.77857	0.99379
15	0.679182	0.90732	0.77402	0.98865
16	0.675058	0.90256	0.76962	0.98368
17	0.66896	0.89551	0.76311	0.97632
18	**0.667174**	**0.89344**	**0.7612**	**0.97416**
19	0.986066	0.99305	0.98884	0.99415
20	0.971899	0.97883	0.97465	0.97992
21	0.969224	0.97615	0.97197	0.97723
22	0.966736	0.97365	0.96948	0.97474
23	0.919699	0.97054	0.94079	0.96934
24	0.894699	0.96046	0.92502	0.94368
25	0.882726	0.96322	0.9128	0.93137
26	0.806123	0.93494	0.86736	0.99695
27	0.797415	0.93312	0.8621	0.99576
28	0.758824	0.91936	0.84582	0.9937

29	0.732772	0.91131	0.83547	0.9937
30	0.721842	0.91212	0.82999	0.99534
31	0.708873	0.89753	0.81604	0.99653
32	0.706141	0.89444	0.8131	0.99323
33	0.705272	0.89346	0.81217	0.9922

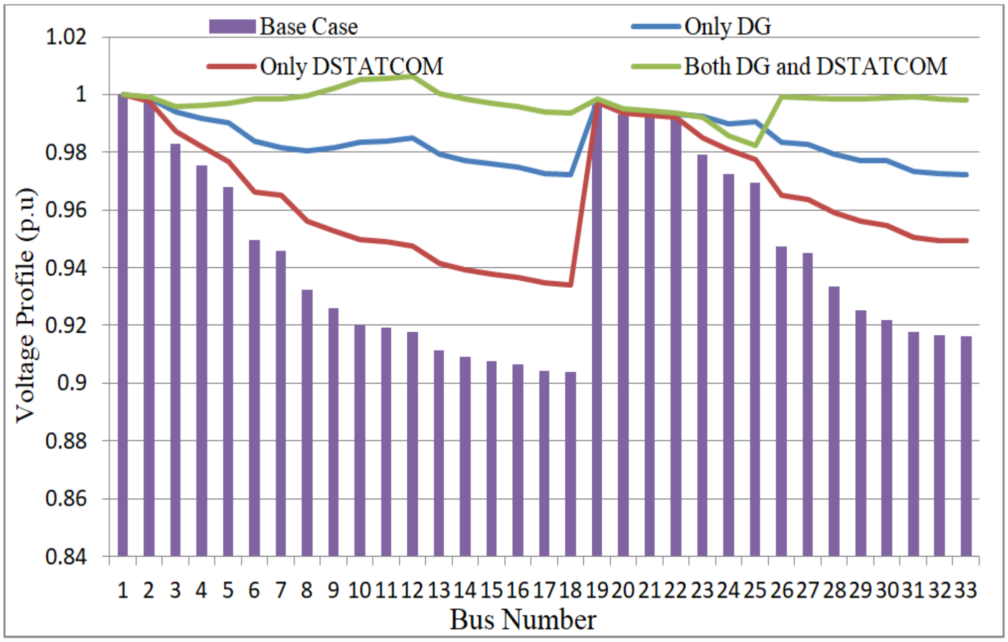
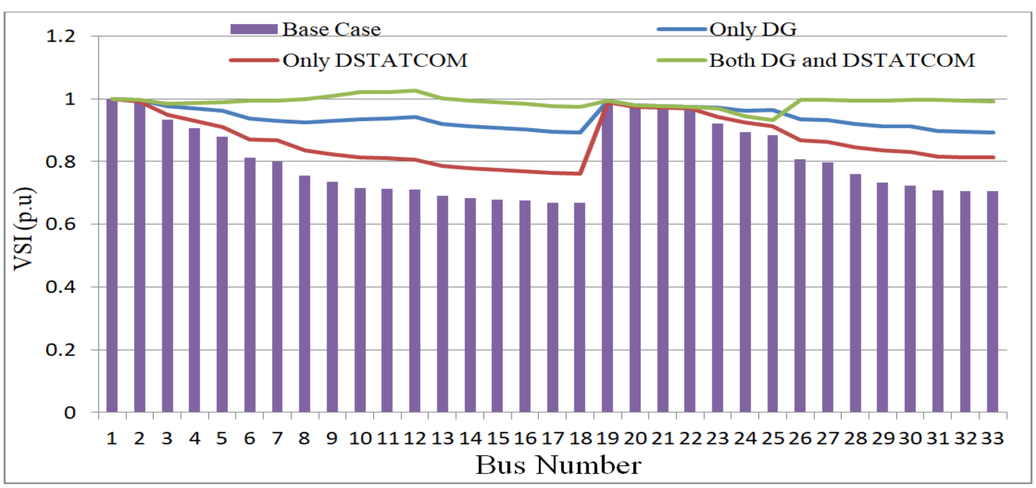


Fig. 4. Voltage profile for 33-node RDS with different cases



VSI for 33-node RDS with different cases

The optimized voltage profile for three different cases with base is displayed in Table 1 and graphically shown in fig. 4. The minimum voltage of base case and proposed GTO is 0.9037 (p.u) and 0.99348 (p.u) with location of 18 respectively. Similarly the voltage stability index for various cases with base is reported in Table 2 and graphically displayed in fig. 5. The minimum VSI of base case and proposed GTO is 0.667174 (p.u) and 0.97416 (p.u) with location of 18 respectively. It is clear that the proposed GTO approach does better performance for enhancing the minimum voltage and VSI by proper allocation and sizing the DG and DSATCOM.

Table 3 Simulation results of 33-node radial distribution system with DG units

Only DG is connected (Case 2)		
Parameters	**FA-SCAC-PSO**	**GTOA (Proposed method)**
Optimal location of DG units	13 25 30	12 25 30
Sizing of DG units	0.8181 0.7033 1.0344	1.0859 0.7019 1.0895
Active Power Loss Level (APLL) (%)	74.0075	73.548
Net Saving Level (NSL) (%)	64.8786	64.035
Short Circuit Level (SCL) (%)	5.9531	6.4970
Voltage Deviation Level (VDL) (%)	65.1934	67.899
Environmental Pollution Reduction Level (EPRL) (%)	23.9088	18.877
Multi obictive function (MOF) (%)	51.4903	51.638

Table 4 Simulation results of 33-node radial distribution system with DSTATCOM

Only DSTATCOM is connected (Case 3)		
Parameters	**FA-SCAC-PSO**	**GTOA (Proposed method)**
Optimal location of DSTATCOM	14 24 30	30 11 24
Sizing of DSTATCOM	0.4021 0.5531 1.0594	1.0832 0.55362 0.55805
Active Power Loss Level (APLL) (%)	60.3891	60.239
Net Saving Level (NSL) (%)	34.4071	33.996
Short Circuit Level (SCL) (%)	3.0044	2.9980
Voltage Deviation Level (VDL) (%)	55.0186	53.898
Environmental Pollution Reduction Level (EPRL) (%)	49.5388	49.5300
Multi obictive function (MOF) (%)	41.1029	41.203

Table 5 Simulation results of 33-node radial distribution system with both DG and DSTATCOM

Combined DG and DSATCOM is connected (Case 4)		
Parameters	**FA-SCAC-PSO**	**GTOA (Proposed method)**

Optimal location of Both DG and DSTATCOM	DG: 13 25 30 DSTATCOM: 13 24 30	DG: 12 26 31 DSTATCOM: 30 10 4
Sizing of both DG and DSTATCOM	DG: 0.8963 0.6520 1.0685 STATCOM: 0.3895 0.4762 1.0581	DG: 0.89562 0.79352 0.67983 STATCOM: 0.95039 0.55322 0.29418
Active Power Loss Level (APLL) (%)	93.9877	91.155
Net Saving Level (NSL) (%)	93.6031	89.08
Short Circuit Level (SCL) (%)	8.7664	9.984
Short Circuit Level (VDL) (%)	94.5390	99.986
Environmental Pollution Reduction Level (EPRL) (%)	22.0738	25.856
Multi obictive function (MOF) (%)	69.7066	69.742

The proposed problem is considered as a multi objective function and simulation results are displayed in Table 3, Table 4 and Table 5 respectively. These tables explain the Optimal location of DG and DSTATCOM, Sizing of DG and DSTATCOM, Active Power Loss Level, Net Saving Level, Short Circuit Level, Short Circuit Level, Environmental Pollution Reduction Level and Multi obictive function of the proposed test system. From the Tables 3, 4 and 5, Table 5 (Combined DG and DSATCOM is connected) provide maximized technical, economical and environmental benefit of RDS. The obtained results also compared with FA-SCAC-PSO algorithm to prove the efficiency of the proposed GTO approach. From the comparison, the applied GTO provides improved technical-economic and Environmental Benefit under competitive environment.

5. Conclusions

In this research work, a method based on MOGTO approach has been applied to solve the multi objective optimization problem in RDS. Here, DGs and DSTATCOM is used and properly located in a proposed test system for improving voltage profile, minimize the network losses and techno-economic environmental benefits of RDS. Five different objectives are conceded and effectively improved by proper allocation and sizing of DGs and DSTATCOM using MOGTO algorithm. The projected technique has been implemented on the IEEE 33-node distribution test system with four different cases..The simulated results such as voltage profile, VSI, minimum VSI, active power loss and techno-economic environmental benefits are compared with FA-SCAC-PSO technique. It is evident that the proposed GTO algorithm is one of the best meta-heuristic approaches for solution complex, multi objective nonlinear optimization problems under regulated and deregulated environment.

References:

1. Kumar, S., Mandal, K.K. and Chakraborty, N., (2020). A novel opposition-based tuned-chaotic differential evolution technique for techno-economic analysis by optimal placement of distributed

generation. *Engineering Optimization*, Vol. *52*(2), Feb., pp.303-324.

2. Subbaramaiah, K. and Sujatha, P., (2023). Optimal DG unit placement in distribution networks by multi-objective whale optimization algorithm & its techno-economic analysis. *Electric Power Systems Research*, Vol. 214, Jan., pp.108869.
3. Sultan, M.S., Kazmi, S.A.A., Altamimi, A., Khan, Z.A. and Shin, D.R., (2023). Multi-Objective Optimization-Based Approach for Optimal Allocation of Distributed Generation Considering Techno-Economic and Environmental Indices. *Sustainability*, Vol.15(5), Feb., pp.4306.
4. Ghatak, S.R., Sannigrahi, S. and Acharjee, P., (2018). Optimal placement of DSTATCOM and DG using modified SFLA based technique for techno-economic and environmental benefits. *Recent Advances in Electrical & Electronic Engineering (Formerly Recent Patents on Electrical & Electronic Engineering)*, Vol.11(3), Sep., pp.334-347.
5. Injeti, S.K. and Kumar, T.V., (2018). A WDO framework for optimal deployment of DGs and DSCs in a radial distribution system under daily load pattern to improve techno-economic benefits. *International Journal of Energy Optimization and Engineering (IJEOE)*, Vol.7(2), Apr., pp.1-38.
6. Ghatak, S.R., Sannigrahi, S. and Acharjee, P., (2017). Comparative performance analysis of DG and DSTATCOM using improved PSO based on success rate for deregulated environment. *IEEE Systems Journal*, Vol.12(3), Apr., pp.2791-2802.
7. Amewornu, E.M. and Nwulu, N.I., (2021). A framework for the techno-economic and reliability analysis of grid connected microgrids. *Journal of Engineering, Design and Technology*, Vol.19(3), June, pp.659-685.
8. Hassan, A.S., Othman, E.A., Bendary, F.M. and Ebrahim, M.A., (2021). Distribution systems techno-economic performance optimization through renewable energy resources integration. *Array*, Vol.9, March, pp.100050.
9. Saw, B.K., Bohre, A.K., Jobanputra, J.H. and Kolhe, M.L., (2022). Solar-DG and DSTATCOM concurrent planning in reconfigured distribution system using APSO and GWO-PSO based on novel objective function. *Energies*, Vol. 16(1), pp.1-38.
10. Sannigrahi, S., Roy Ghatak, S. and Acharjee, P., (2019). Strategically incorporation of RES and DSTATCOM for techno-economic-environmental benefits using search space reduction-based ICSA. *IET Generation, Transmission & Distribution*, Vol.13(8), Apr., pp.1369-1381.
11. Nagaballi, S. and Kale, V.S., (2021). A metaphor-less based AI technique for optimal deployment of DG and DSTATCOM considering reconfiguration in the RDS for Techno-Economic benefits. *Journal of Intelligent & Fuzzy Systems*, Vol.41(5), pp.5719-5729.
12. Abd El Sattar, M., Abd El Hamed, A.M., Elbaset, A.A. and Ebeed, M., (2021), Optimal sites and sizes of DSTATCOM and PV based DG using Manta Ray Foraging Optimizer, *International Journal For Innovative Engineering and Management Research*, Vol. 10 (8), Aug., Pages: 71-79.
13. Lasmari, A., Zellagui, M., Gupta, A.A., El-Sehiemy, R.A. and Chenni, R., (2020), November. Multi-objective salp swarm algorithm for performance enhancement of electrical distribution system including DG and DSTATCOM simultaneously. In *the 4th International Conference on Artificial Intelligence in Renewable Energetic Systems (IC-AIRES). Tipasa, Algeria*, pp. 22-24.
14. Sannigrahi, S., Ghatak, S.R. and Acharjee, P., (2018), Optimal planning of distribution network with DSTATCOM and WTDG using RTO technique. In *2018 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)*, pp. 1-6.
15. Zhu, S., Wu, Q., Jiang, Y., & Xing, W. (2021). A novel multi-objective group teaching optimization algorithm and its application to engineering design. *Computers & Industrial Engineering*, *155*, 107198,
16. Zhang, Y., & Jin, Z. (2020). Group teaching optimization algorithm: A novel metaheuristic method for solving global optimization problems. *Expert Systems with Applications*, *148*, 113246