International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 02 Issue: 02 February 2024
Page No: 18 - 25
https://irjaeh.com

Optimal allocation of Combined DG and DSTATCOM for Improving Voltage Stability and Economical Benefits of Distribution System

Ram Prasad Kannemadugu[1], V. Adhimoorthy[2], A. Lakshmi Devi[3], K. Asokan[4]

[1]Research Scholar, Department of Electrical Engineering, Annamalai University, Annamalai Nagar, Tamil Nadu, India.

[2,4]Associate Professor, Department of Electrical and Electronics Engineering, Government College of Engineering, Bargur, Tamil Nadu, India.

[3]Professor, Department of Electrical and Electronics Engineering, SV University College of Engineering, SV University, Andhra Pradesh, India.

Emails: *ramprasad2102@gmail.com[1], adhisuganthi@gmail.com[2],energylak123@yahoo.com[3], asokanee@gmail.com[4]*

Abstract

In the vertically integrated power sector, the distribution system serves as the link between customers and the transmission network. Different load models, including industrial, residential, and commercial, are taken into account within the distribution systems. The loading pattern of these load models varies with a large range according to the peak hours. During peak load conditions, the voltage magnitude of some nodes exceeds the permissible limit of voltage value. It affects the voltage stability of the distribution system, leading to decreased reliability, heightened power losses, diminished voltage stability, and other safety concerns. Optimal placement of capacitors, applying DGs, using FACTS devices, and Distribution Network reconfigurations are possible to reduce the power loss. This paper focuses on reducing power loss and enhancing the voltage profile and stability of the system. It addresses the technical, economic, and environmental benefits of the distribution system through appropriate placement and sizing of DG and DSTATCOM units in a coordinated manner. The issue is approached as a Multi-Objective Optimization Problem (MOP) and is tackled through the application of the Group Teaching Optimization (GTO) algorithm, an innovative metaheuristic method. A numerical illustration utilizing an IEEE 69-node system is examined, and the simulated outcomes are presented in tabular form. These results are then juxtaposed with findings from comparable methodologies outlined in existing literature.

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

1. Introduction

In the regulated power industry power distribution networks commonly employ with radial structure. Due to inappropriate design and planning of distribution networks the power system would face some problems. Incorporating diminished reliability, amplified power loss, diminished voltage stability, and various safety concerns, the distribution system grapples with multiple issues. Over time, power loss minimization has remained a significant priority for distribution system operators. To address this, strategies such as capacitor placement, deployment of Distributed Generators (DGs), utilization of Flexible AC Transmission Systems (FACTS) devices, and Distribution Network Reconfiguration (DNR) have been employed. The Voltage Stability Index (VSI) plays a crucial role in identifying the best locations for capacitors and DG units to enhance overall system voltage stability. Additionally, it works towards reducing network losses and improving the cost savings of the system. [1]. Researchers developed diverse strategies to maximize the techno-economic benefits of radial distribution systems (RDS). Optimal positioning of DG units within an RDS can mitigate power losses and improve the voltage profile of the distribution network, employing an opposition-based tuned-chaotic differential evolution method. [1], Multi-Objective Whale Optimization Algorithm [2] and ant Lion Optimization [3] have been applied to enhance the techno-economic environmental benefits. Modified Shuffled Frog Leaping Algorithm [4], Wind-driven optimization [5], and PSO technique with adaptive inertia weight [6]. The methods employed have been utilized for determining the aim is to optimize the sizing and placement of DGs and DSTATCOM units within RDS, to maximize technical, economic, and environmental benefits. [7]. Metaphor-less-based Artificial intelligence [10] the approach is utilized to decrease power losses, enhance the voltage profile, and improve the voltage stability index of the RDS. This is done while also considering the overall economic benefit through network reconfiguration and the integration of Distributed Generators. (DGs) and Distribution Static Compensator (DSTATCOM) units. (DSTATCOM) units placed in optimal positions by applying the Rao-1 method [5] and Gravitational Search Algorithm [11]. Manta Ray Foraging Optimization [12] and Multi-Objective Salp Swarm Algorithm [13] have been used to determine the parameters that comprise Real Power Loss, Short Circuits, Voltage Deviation, Net Savings, and Environmental Pollution Reduction levels. By strategically allocating distributed static compensators and wind [8] turbine-type distributed generation within the distribution network, the goal is to effectively tackle the challenge of optimal deployment [9]. This aims to enhance the voltage profile, minimize losses, maximize economic benefits, and reduce pollution levels, employing the rooted tree optimization technique. [14] To mitigate concerns related to voltage stability and maximize economic benefits in radial distribution systems (RDS), this study employs an established framework utilizing the GTO algorithm, known for its efficacy. The planning considerations specific to RDS are thoroughly investigated to assess the proposed approach. Simulation results validate the algorithm's effectiveness in identifying optimal network reconfiguration, along with placement and sizing of distributed generation (DG) and Distribution Static Synchronous Compensator (DSTATCOM) in radial distribution systems [16].

2. Problem Formulation

2.1 Voltage Stability Indices (VSI)

The VSI of the proposed problem can be mathematically reported as can be defined as [9],

$$VSI(m2)=|V(m1)|^4-4.0\{P(m2)x(jj)-Q(m2)r(jj)\}^2 -4.0\{P(m2)r(jj)+Q(m2)x(jj)\}|V(m1)|^2 \quad (1)$$

2.2 Objective functions

The objective of this study is to offer a novel MOF that maximizes APL, NSL, SCL, VDL, and EPRL to solve the challenge of determining the ideal size and position of DG and/or DSTATCOM units. This formulation can be expressed as follows:

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

2.3 Equality constraints

The power balance equations are used to describe equality constraints:

$$P_G + P_{DG} = P_D + P_{LOSS} \quad (3)$$

$$Q_G + Q_{STATCOM} = Q_D + Q_{LOSS} \quad (4)$$

2.4 Inequality constraints of distribution line

$$Bus\ Voltage : V_{min} \leq |V_i| \leq V_{max} \quad (5)$$

$$Voltage\ drop\ limitation : |V_1 - V_j| \leq \Delta V_{max} \quad (6)$$

$$Line\ Capacity : |S_{ij}| \leq |S_{max}| \quad (7)$$

3. Group Teaching Optimization (Gto) Algorithm

3.1 Proposed GTO algorithm

The suggested GTOA is regarded as an excellent concept that aims to enhance the class's collective

IRJAEH

International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 02 Issue: 02 February 2024
Page No: 18 - 25
https://irjaeh.com

learning abilities and knowledge by modeling the group teaching process. As there are 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 [15] and the structure of the GTO is shown in Figure 1. This GTO has four phases and is mathematically represented as follows.

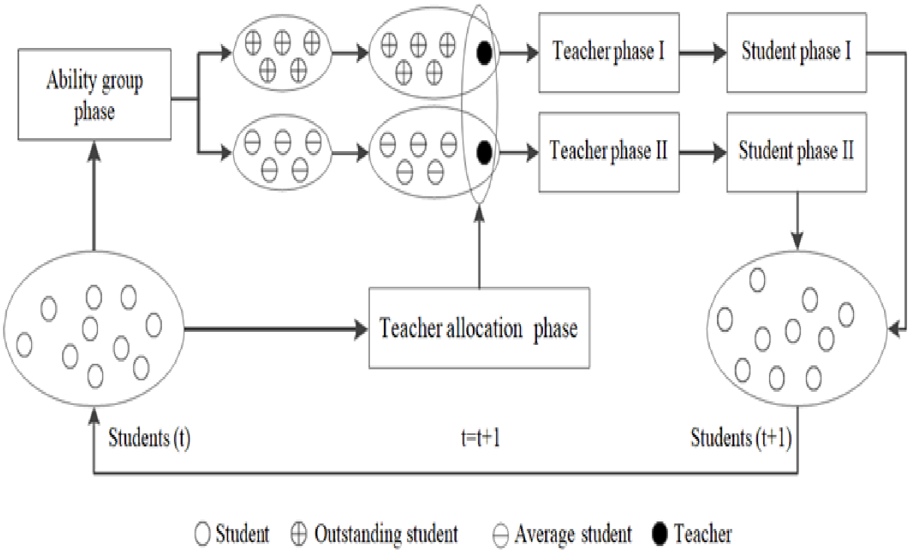

Figure 1 **Framework structure of the GTO algorithm**

3.2 Mathematical formulation of GTO algorithm

3.2.1 Ability grouping phase

Without compromising generality, it is anticipated that the class's collective knowledge will be dispersed properly. The normal distribution can be described as

$$f(x) = \frac{1}{\sqrt{2\pi\delta}} e^{\frac{-(x-u)^2}{2\delta^2}} \quad (8)$$

3.3 Teacher phase

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

Teacher phase I

$$x_{teacher,i}^{t+1} = x_i^t + a \times \left(T^t - F \times \left(b \times M^t + c \times x_i^t\right)\right) \quad (9)$$

$$M^t = \frac{1}{N}\sum_{i=1}^{N} x_i^t \quad (10)$$

$$b + c = 1 \quad (11)$$

Teacher phase II

$$x_{teacher,i}^{t+1} = x_i^t + 2 \times d \times \left(T^t - x_i^t\right) \quad (12)$$

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.

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

3.3.1 Student phase

The student phase of the GTO is represented as

$$x_{teacher,i}^{t+1} = \begin{cases} x_{teacher,i}^{t+1} + e \times \left(x_{teacher,i}^{t+1} - x_{teacher,j}^{t+1}\right) + g \times \left(x_{teacher,i}^{t+1} - x_i^t\right), & f\left(x_{teacher,i}^{t+1}\right) < f\left(x_{teacher,j}^{t+1}\right) \\ x_{teacher,i}^{t+1} - e \times \left(x_{teacher,i}^{t+1} - x_{teacher,j}^{t+1}\right) + g \times \left(x_{teacher,i}^{t+1} - x_i^t\right), & f\left(x_{teacher,i}^{t+1}\right) \geq f\left(x_{teacher,j}^{t+1}\right) \end{cases} \quad (14)$$

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

$$x_i^{t+1} = \begin{cases} x_{teacher,i}^{t+1}, & f\left(x_{teacher,i}^{t+1}\right) < f\left(x_{student,i}^{t+1}\right) \\ x_{student,i}^{t}, & f\left(x_{teacher,i}^{t+1}\right) \geq f\left(x_{student,i}^{t+1}\right) \end{cases} \quad (15)$$

3.3.2 Teacher Allocation Phase

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

$$T^t = \begin{cases} x_{first}^t, & f\left(x_{first}^t\right) \leq f\left(\frac{x_{first}^t + x_{second}^t + x_{third}^t}{3}\right) \\ \frac{x_{first}^t + x_{second}^t + x_{third}^t}{3}, & f\left(x_{first}^t\right) > f\left(\frac{x_{first}^t + x_{second}^t + x_{third}^t}{3}\right) \end{cases} \quad (16)$$

3.4 Implementation of GTO algorithm

A multi-objective GTO algorithm is used to assess the techno-economic and environmental benefits of the suggested test system. This strategy includes reducing power loss, improving node voltage, and placing and sizing DGs and DSTATCOM units in radial distribution systems in the best possible ways [17].

a) 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.
b) Execute the load flow analysis using distribution load flow for the base case.
c) Determine and fix the number of DG and DSTACOM are to be used in RDS
d) 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 the problem, and fitness functions. The population of GTO can be mathematically represented by

$$X^t = \left[x_1^t, x_2^t, \ldots\ldots, x_N^t\right]^T = \begin{bmatrix} x_{1,1}^t & x_{1,2}^t & \cdots & x_{1,D}^t \\ x_{2,1}^t & x_{2,2}^t & \cdots & x_{2,D}^t \\ \vdots & \vdots & & \vdots \\ x_{N,1}^t & x_{N,2}^t & \cdots & x_{N,D}^t \end{bmatrix} \quad (17)$$

$$x_{i,j}^t = l_i + \left(u_i - l_i\right) \times \mathrm{K} \quad (18)$$

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

$$fitness = \frac{1}{1 + objective\ function} \quad (19)$$

g) The fitness values of individuals are calculated and the optimal solution Gt is selected. The current number of function evaluations Tcurrent current is updated using

$$T_{Current} = T_{Current} + N \quad (20)$$

h) If the current figure of operation assessment Tcurrent current is greater than the maximum number of operation evaluations Tmax, the algorithm ends and the optimal solution GT is outputted. Otherwise, go to step 9.
i) Teacher allocation phase, the first three best individuals are selected. Then the teacher's Tt is calculated.
j) Update the position of all phases.
k) The fitness values of individuals are calculated using equation (21).

$$T_{Current} = T_{Current} + 2N + 1 \quad (21)$$

l) Compute the present position of all phases of the multi-objective GTO algorithm.
m) Check all constraints and the maximum number of iterations reached if yes move to the next step. Otherwise, go to step 6.
n) Print the obtained results and stop

4. Results and Discussions

The performance of ALO is tested on a large-scale test of a 69- 69-node system to enhance the voltage stability and reduce the network losses. The system load demand is 3.80 MW and 2.69 MVAR. The line data and bus data of the projected test system are taken from the reference [12]. This system has one main feeder and seven laterals as shown in Figure 2. The applied GTO determines the best location and optimal value of both DG and DSTATCOM. Initially, DG and DSTATCOM are separately considered then both components are applied and find the optimal solutions. The voltage profile of combined DG and DSTACOM is graphically reported in Figure 3. The proposed problem is considered as a multi-objective function and simulation results are displayed in Table 1, Table 2, and Table 3 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-objective function of the proposed test system [18]. The Convergence characteristics of the 69-node system are displayed in Figure 4.

Table 1 Simulation results of 69-node radial distribution system with DG units

Parameters	FA-SCAC-PSO	GTOA (Proposed method)
Size in MW (Bus)	0.3248 (12) 0.3503 (21) 1.6719 (61)	0.80315 (16) 0.34609 (64) 1.5635 (61)
APLL (%)	76.2320	75.091
NSL (%)	68.8215	66.828
SCL (%)	1.1202	2.2202
VDL (%)	64.4333	67.833
EPRL (%)	27.3952	22.423
MOF (%)	52.1346	52.146

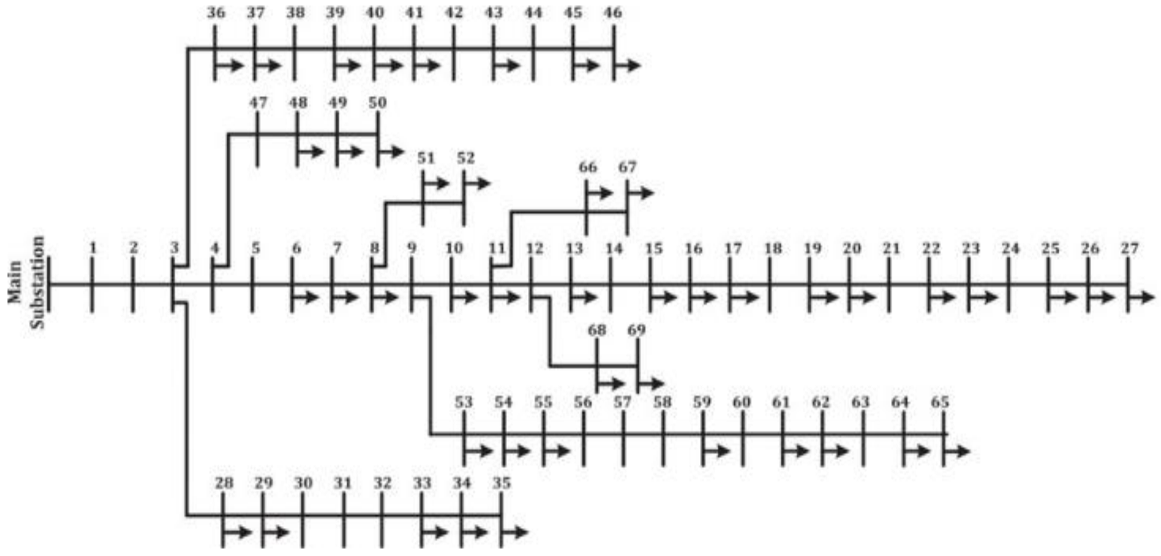

Figure 2 Single line diagram of the 69-node radial distribution system

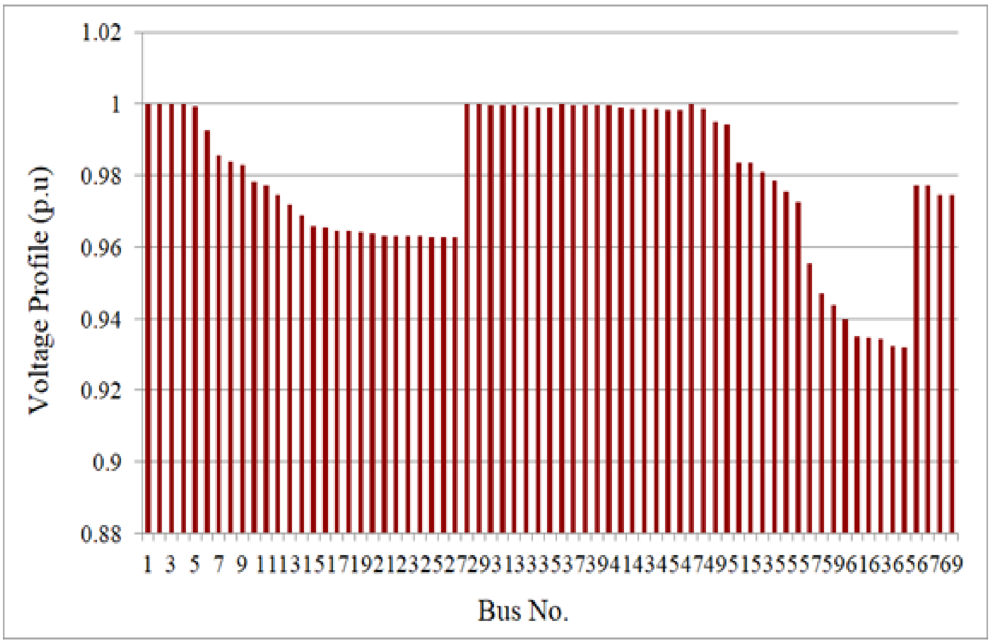

Figure 3 Voltage profile of 69-node radial distribution system

Table 2 Simulation results of 69-node radial distribution system with DSTATCOM

Parameters	FA-SCAC-PSO	GTOA (Proposed method)
Size in MW (Bus)	0.3868 (11) 0.2355 (20) 1.2367 (61)	0.42633 (18) 1.3292 (61) 0.80619 (8)
APLL (%)	60.7892	60.311
NSL (%)	35.4971	34.192
SCL (%)	0.3900	0.3820
VDL (%)	55.3286	55.098
EPRL (%)	49.5052	49.518
MOF(%)	40.9729	40.98

Table 3 Simulation results of 69-node radial distribution system with both DG and DSTATCOM

Parameters	FA-SCAC-PSO	GTOA (Proposed method)
Size in MW (Bus)	DG: 0.3559 (17) 1.7539 (61) 0.4070 (69) STATCOM: 0.4007 (11) 0.2673 (17) 1.1588 (61)	DG: 0.55334 (18) 1.3411 (9) 0.31094 (10) STATCOM: 0.18698 (10) 1.3285 (9) 0.33745 (17)
APLL (%)	97.7573	97.433
NSL (%)	97.7058	97.366
SCL (%)	1.5814	1.5880
VDL (%)	96.0002	95.780
EPRL (%)	24.1774	24.539
MOF(%)	70.5975	70.631

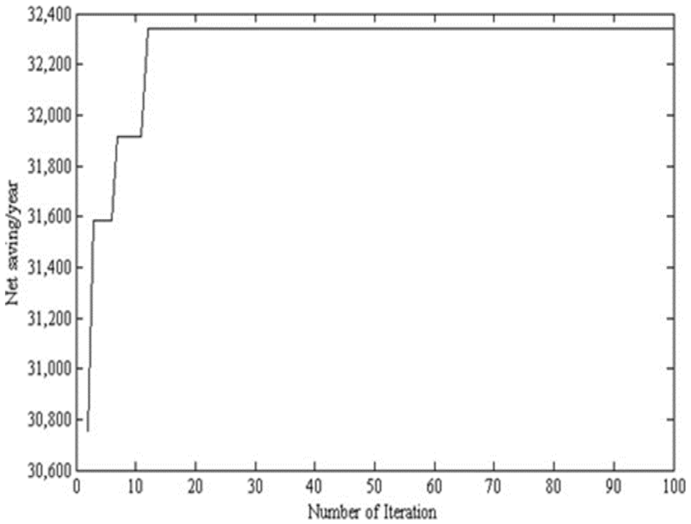

Figure 4 Convergence characteristics of 69-node system

From Tables 1, 2, and 3 (Combined DG and DSATCOM are connected) provides maximized technical, economic, and environmental benefits of RDS. The obtained results were also compared with the 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 Benefits in a competitive environment [19].

Conclusions

This paper solves the multi-objective voltage stability problem using the MOGTO approach. The compensators of DGs and DSTATCOM are used to enhance the voltage profile of RDS/ the projected technique has been implemented on the IEEE 69-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 the FA-SCAC-PSO technique. The proposed GTO algorithm is one of the best meta-heuristic approaches for solving complex, multi-objective nonlinear optimization problems in under-regulated and deregulated environments.

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 & and 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 the success rate for the 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 the novel objective function. Energies, Vol. 16(1), pp.1-38.

[10]. Sannigrahi, S., Roy Ghatak, S. and Acharjee, P., (2019). Strategically incorporate 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.

[17]. Nayak, Ganesh Ch, et al. "Novel approach for the selective dispersion of MWCNTs in the Nylon/SAN blend system." Composites Part A: Applied Science and Manufacturing 43.8 (2012): 1242-1251.

[18]. Nayak, Ganesh Ch, R. Rajasekar, and Chapal Kumar Das. "Effect of SiC coated MWCNTs on the thermal and mechanical properties of PEI/LCP blend." Composites Part A: Applied Science and Manufacturing 41.11 (2010): 1662-1667.

[19]. Mukherjee, M., et al. "Improvement of the properties of PC/LCP blends in the presence of carbon nanotubes." Composites Part A: Applied Science and Manufacturing 40.8 (2009): 1291-1298.