Optimal reactive power dispatch using modified-ant lion optimizer with flexible AC transmission systems devices

Sela Naga Venkata Sri Krishna Chaitanya[1,3], R. Ashok Bakkiyaraj[2], Bathina Venkateswara Rao[3], Kalikrishnan Jayanthi[4]
[1]Department of EEE, Annamalai University, Tamil Nadu, India
[2]Department of EE, Annamalai University, Chidambaram, Tamil Nadu, India
[3]Department of EEE, V R Siddhartha Engineering College, deemed to be University, Andhra Pradesh, India
[4]Department of Computer and Information Science, Annamalai University, Tamil Nadu, India

Article Info

Article history:

Received Jan 29, 2023
Revised Jul 20, 2024
Accepted Sep 28, 2024

Keywords:

Ant-lion optimizer
Flexible AC transmission systems
Modified ant-lion optimizer
Power loss
Voltage deviation

ABSTRACT

This study focuses on reactive power planning in the IEEE30-bus test system, specifically involving the integration of flexible AC transmission systems (FACTS) within the utility system. The primary objective is to minimize power loss and voltage deviation. To address this, a recently developed optimization algorithm called modified ant-lion optimizer (MALO) is applied to solve the optimal reactive power dispatch (ORPD) problem on the IEEE 30-bus system. A comparative analysis is conducted between the results obtained with and without FACTS devices. The findings reveal that the utilization of FACTS devices leads to significantly improved outcomes compared to scenarios without FACTS devices. Among the FACTS devices studied, the unified power flow controller (UPFC) demonstrates superior performance compared to the static synchronous compensator (STATCOM) and interline power flow controller (IPFC).

Corresponding Author:

Bathina Venkateswara Rao
Department of EEE, V R Siddhartha Engineering College, deemed to be University
Vijayawada, Andhra Pradesh, India
Email: drbvrao@vrsiddhartha.ac.in

1. INTRODUCTION

Optimal power planning with flexible AC transmission systems (FACTS) devices in synchronization with volt-ampererating (VAR) has become anessential component for the safe and efficient operation of power systems. To achieve a significant voltage profile, the optimal reactive power dispatch (ORPD) [1], [2] aims to be as energy efficient as possible, while maintaining acceptable voltage profiles. The control variables are finely tuned to achieve this. To make the voltage profile betterinthe power system, several voltage control devices have been incorporated, including transformers that change the voltage, shunt capacitors [3], [4], static VAR compensators (SVCs) [5], thyristor-controlled series compensators (TCSCs) [6], [7], and thyristor-controlled phase shifters (TCP). Control variable settings in IEEE30 bus, IEEE57 bus, and IEEE118 bus systems [8] produce complex constraint optimization problems. The effect of such optimization on system performance is significant because it reduces losses, improves voltage profiles, increases network load capacity, increases voltage stability, and reduces fuel costs. We find that the stakeholders are more interested in achieving these objectives, particularly through the integration of FACTS into legacy power systems. The installation of FACTS is recommended for weak buses in power systems based on modal analysis. The voltage collapse proximity indicator (VCPI) is also tested to improve the voltage stability index. To solve optimal power planning problems, some of the authors employed analytical methods [9], genetic algorithms (GA) [10], current injection, and power injection models of FACTS. Static synchronous compensator (STATCOM) is one of the FACTS devices that is used to mitigate the current variations in the power flow. In the same line of power flow, unified power flow controller (UPFC) is employed to reduce and make up changes in current and voltage. Interline power flow controller (IPFC) is used in the various lines of power flow to lessen and correct variations in voltage and current. To minimize voltage deviation, active power losses, reactive power control, or manage margins and congestion, FACTS devices are installed at optimal locations [11], [12].

For optimizing FACTS allocation, some computational techniques are suggested, including artificial neural networks (ANN) [13], fuzzy logic (FL) [14], artificial neural networks and fuzzy inference systems (ANFIS) [15], GA, gravitational search algorithms (GSA) [16], population-based techniques-particle swarm optimization (PSO) [17], Evolutionary search algorithms [18], Darwin's theory baseddifferential evolution [19], tabu-search algorithms (TSA) [20], simulated algorithms (SA) [21], firefly algorithm (FA) [22], artificial bee colonies [23], quasi-ORPDositional chemical reaction optimization, improved GSA, and chaotic krill herd algorithms. Because these algorithms have not been exploited from the perspective of ORPD, as well as FACTS, it is important to explore stochastic and search techniques [24]. An implementation of a hybrid algorithm combining ant colony optimization (ACO) and lion hunt optimization (LHA) has been proposed recently, incorporating its calculus in the internal structure of optimizers. For the solution of ORPD, we can cite the ACO with LHA. Many power system problems have been solved with these methods. But this work suggests the use of calculus tools with intelligent strategies to deal with optimization problems in the energy sector. It is intended to examine the application of antlion optimization (ALO) to electric power networks incorporating FACTS. Different contingency situations may lead to voltage collapse due to weak buses. We implement an efficient solution for ORPD problems based on a modified version of the ALO, the modified ant-lion optimizer (MALO). As part of the algorithm, control variables such as the STATCOM, UPFC, IPFC, transformer tap positions, and bus voltages are determined to satisfy power demand. A voltage deviation and a power loss minimization objective function are considered under MALO.

Accordingly, we can summarize the workflow as:
- Incorporating FACTS into optimization as a cutting-edge approach in resolving ORPD.
- By adding MALO to ORPD problems, it is possible to reduce total voltage variations and power losses while still meeting operating requirements.
- Analysis of the MALO's performance is done based on IEEE 30 bus case studies with ORPD.
- Statistical analyses consistently exemplify the robustness, stability, and consistency of the proposed MALO.

The article describes its structure as follows: a fitness function is presented for ORPD problems in section 2. The mathematical model of FACTSis discussed in section 3. Section 4 contains comprehensive descriptions of both the MALO and the scheme. Section 5 provides detailed comparisons with statistical evaluations. Section 6 wraps up the entire essay with a summary of the key findings.

2. PROBLEM FORMULATION

The control variables may be optimized with MALO. In addition, this includes the STATCOM, UPFC, and IPFC size concerning the system evaluation functions, as well as the tap changer settings. Following are the objectives, constraints, and expressions.

2.1. Optimal fit function for minimizing power loss

Below is the fitness function utilized to minimize power loss in a power distribution system:

$$Min\ F(x1,x2)=P_{Loss}=\sum_{r=1}^{R} g_r[V_i^2+V_j^2-2V_iV_j\cos(\delta_i-\delta_j)] \quad (1)$$

The x_1 and x_2 in (1) is realized as:

$$x_1=\begin{bmatrix} V_{L1},V_{L2},V_{L3},\dots,V_{LN}, \\ Q_{G1},Q_{G2},Q_{G3},\dots,G_{GN}, \\ Z_{L1},Z_{L2},Z_{L3},\dots,Z_{LN}, \end{bmatrix}, \qquad x_2=\begin{bmatrix} V_{G1},V_{G2},V_{G3},\dots,V_{GN}, \\ Q_{C1},Q_{C2},Q_{C3},\dots,G_{CN}, \\ T_1,T_2,T_3,\dots,T_N, \\ STATCOM_1,STATCOM_2,\dots,STATCOM_N, \\ UPQC_1,UPQC_2,UPQC_3,\dots,UPQC_N, \\ IPQC_1,IPQC_2,IPQC_3,\dots,IPQC_N, \end{bmatrix}$$

A loss minimization function is represented by F (x_1, x_2).
- Total transmission lines are represented as R.

- The sending end voltage is V_i and the receiving end voltage is V_j.
- The conductance of the line is represented as g_r.
- The sending end voltage angle δ_i and the receiving end voltage angle δ_j are the respective voltage angles.
- The vector of control variables x_1 consists of the load voltages V_{L1}, VL_2, ..., V_{LN}; reactive power of the generator Q_{G1}, Q_{G2}, ..., Q_{GN} and line loading Z_{L1}, Z_{L2}, ..., Z_{LN}.
- The vector of control variables x_2 consists of the reactive power compensators Q_{C1}, Q_{C2}, ..., QCN; Generator voltages V_{G1}, V_{G2}, ..., V_{GN}; tap positions of the transformers T_1, T_2, ... T_N; STATCOMs - $STATCOM_1$, $STATCOM_2$, ..., $STATCOM_N$; unified power flow controller (UPFC), $UPFC_1$, $UPFC_2$, ..., $UPFC_N$; IPFC, $IPFC_1$, $IPFC_2$, ..., $IPFC_N$.

The upper and lower ranges for the control variables are presented in Table 1.

Table 1. Control variable boundaries

Control variables	IEEE 30 bus system	
	Max	Min
Voltage	1.1	0.9
Transformer tap	1.06	0.94
Capacitance	5	0

The constraints of equality are as (2) and (3):

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{N_{Bus}} V_j \begin{bmatrix} B_{ij} sin(\delta_i - \delta_j) \\ +G_{ij}\, cos(\delta_i - \delta_j) \end{bmatrix} = 0 \tag{2}$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{N_{Bus}} V_j \begin{bmatrix} B_{ij} sin(\delta_i - \delta_j) \\ +G_{ij}\, cos(\delta_i - \delta_j) \end{bmatrix} = 0 \tag{3}$$

The constraints in inequalities of STATCOM, UPFC, and IPFC boundaries, reactive power, generator voltage and transformer's tap position settings are shown as (4) to (9) [25], [26]:

$$STATCOM_i^{min} \leq STATCOM_i \leq STATCOM_i^{max}, i = 1, 2, \dots, N_{STATCOM} \tag{4}$$

$$UPFC_i^{min} \leq UPFC_i \leq UPFC_i^{max}, i = 1, 2, \dots, N_{UPFC} \tag{5}$$

$$Q_{ci}^{min} \leq Q_{ci} \leq Q_{ci}^{max}, i = 1, 2, \dots, N_C \tag{6}$$

$$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max}, i = 1, 2, \dots, N_{PV} \tag{7}$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max}, i = 1, 2, \dots, N_{PV} \tag{8}$$

$$T_i^{min} \leq T_i \leq T_i^{max}, i = 1, 2, \dots, N_T \tag{9}$$

Where, i_{th} bus active supply and demand are P_{Gi} and P_{Di} respectively; i_{th} bus reactive supply and demand are Q_{Gi} and Q_{Di} respectively and N_T, N_{UPFC}, N_{IPFC}, and N_C are the corresponding numbers of transformers, UPFCs, IPFCs, and shunt capacitors.

2.2. Voltage deviation fitting function

Maintaining a constant voltage level is crucial for ensuring system stability. From a mathematical perspective, the reduction of voltage deviation (V_D) is defined as (10):

$$V_D = \sum_{i=1}^{N_{BUS}} |V_i - 1.0| \tag{10}$$

Where N_{BUS} is the number of buses and V_i is i_{th} bus voltage.

3. FACTS DEVICE MODEL FROM A MATHEMATICAL PERSPECTIVE

Solid-state devices enable the maintenance of desired voltage levels by eliminating line losses, rerouting the network, and reducing faults [27]. By using FACTS, electric power networks can be regulated with respect to current, voltage, phase angle, series and shunt impedance. The UPFC and the IPFC belong to the FACTS family of devices [28]. They can be used as hybrid stunt and series in line and interline compensating devices respectively [29]. The impact of the UPFC and IPFC mathematical models after being included into the network is explored in the following section.

3.1. Static synchronous compensator mathematical modeling

Consequently, by utilizing the static model depicted in Figure 1, Vishnu and K. [30] successfully computed the total active and reactive power of STATCOM:

$$P_{STATCOM} = P_{sh} \tag{11}$$

$$Q_{STATCOM} = Q_{sh} \tag{12}$$

where,

$$P_{sh} = S_{sh} \cos\theta_{sh} \; and \; Q_{sh} = S_{sh} \sin\theta_{sh} \tag{13}$$

Further θ_{Sh} are determined in

$$\theta_{Sh} = \tan^{-1}\left(\frac{\cos(Ø-\delta)-\cos(Ø)}{\sin(Ø-\delta)}\right) + 90^{\circ}\text{-}\delta \tag{14}$$

As a result of the installation of the STATCOM between buses in the network, the Y_{bus} equation matrix is modified as (15):

$$Y_{bus}^{STACOM} = Y_{bus} + \begin{bmatrix} 0 & 0 & 0 & \ldots & 0 & 0 \\ 0 & \Delta y_{sr} + \Delta y_{sh} & 0 & \cdots & -\Delta y_{sr} & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \cdots & \vdots & \vdots \\ 0 & -\Delta y_{sr} & 0 & \cdots & \Delta y_{sr} & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 \end{bmatrix} \tag{15}$$

The value of y_{sr} and y_{sh} representshere the result of STATCOM installation and the admittance value change respectively. A new entry in STATCOM affects branch data because of its presence.

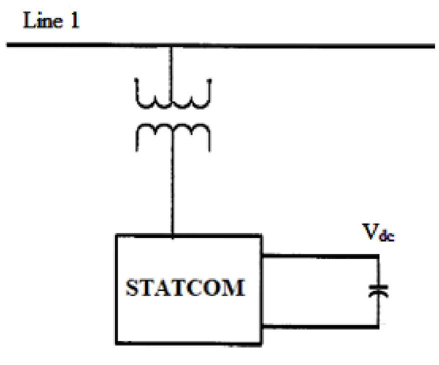

Figure 1. Static model of STATCOM in the utility system

3.2. Unified power flow controller mathematical modeling

Consequently, through the utilization of the static model illustrated in Figure 2, Vishnu and K. [30] estimated the total active and reactive power of UPFC:

$$P_{UPQC} = P_{se} + P_{sh} \tag{16}$$

$$Q_{UPQC} = Q_{se} + Q_{sh} \tag{17}$$

where,

$$P_{se} = S_{se} \cos\theta_{se} \text{ and } Q_{se} = S_{se} \sin\theta_{se} \quad (18)$$

$$P_{sh} = S_{sh} \cos\theta_{sh} \text{ and } Q_{sh} = S_{sh} \sin\theta_{sh} \quad (19)$$

Further, θ_{Se} and θ_{Sh} are determined in

$$\theta_{se} = 180^0 - tan^{-1}\left(\frac{\sin\delta}{1-\cos\delta}\right) = 90^{\circ}+\frac{\delta}{2} \quad (20)$$

$$\theta_{sh} = tan^{-1}\left(\frac{\cos(\emptyset-\delta)-\cos(\emptyset)}{\sin(\emptyset-\delta)}\right) + 90^{\circ}\text{-}\delta \quad (21)$$

As a result of the installation of the UPFC between buses in the network, the Y_{bus} equation matrix is modified as (22):

$$Y_{bus}^{UPQC} = Y_{bus} + \begin{bmatrix} 0 & 0 & 0 & \dots & 0 & 0 \\ 0 & \Delta y_{sr} + \Delta y_{sh} & 0 & \cdots & -\Delta y_{sr} & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \cdots & \vdots & \vdots \\ 0 & -\Delta y_{sr} & 0 & \cdots & \Delta y_{sr} & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 \end{bmatrix} \quad (22)$$

The value of ysr and ysh here represents a result of UPFC installation; the admittance valuechanged. A new entry in UPFC affects branch data because of the UPFC present.

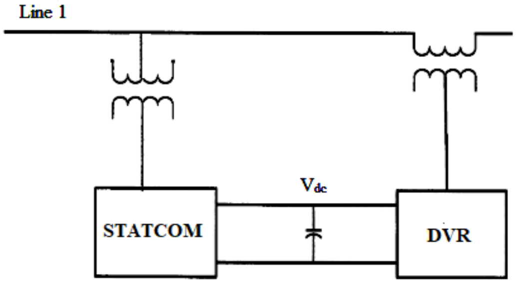

Figure 2. Static model of UPFC in the utility system

3.3. Interline power flow controller mathematical modeling

The IPFC is the extended model of UPFC which is connected between two different lines, unlike the same line between the buses. As a result, Vishnu and K. [30] estimated the IPFC 's total active and reactive power using the static model depicted in Figure 3.

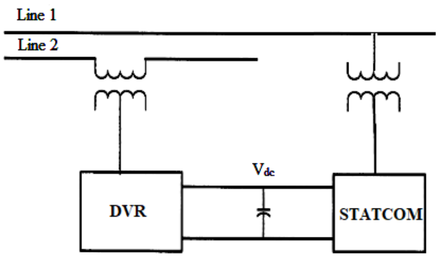

Figure 3. Static model of IPFC in the utility system

As a result of the installation of the IPFC between buses in the network, the Y_{bus} equation matrix is modified as (23):

$$Y_{bus}^{UPQC} = Y_{bus} + \begin{bmatrix} 0 & 0 & 0 & \dots & 0 & 0 \\ 0 & \Delta y_{sr} + \Delta y_{sh} & 0 & \cdots & -\Delta y_{sr} & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \cdots & \vdots & \vdots \\ 0 & -\Delta y_{sr} & 0 & \cdots & \Delta y_{sr} - \Delta y_{sh} & 0 \\ 0 & 0 & 0 & \cdots & 0 & 0 \end{bmatrix} \quad (23)$$

The value of y_{sr} and y_{sh} here represents a result of IPFC installation; the admittance value changed. A new entry in IPFC affects branch data because of the IPFC present.

An optimal FACTS position can only be achieved by a weak bus recognition process. Weak bus recognition is mostly used to place the FACTS devices in the best location possible to give efficient reactive power to the appropriate places. Furthermore, this operation alters the intrinsic attributes of electrical transmission lines, resolves problems associated with voltage instability, reduces line losses, enhances power transmission capacity, and boosts voltage performance. To identify weak buses, a single-line diagram is utilized for load factor analysis. The evaluation is conducted using the IEEE 30 system as the standard.

4. THE PROPOSED MODIFIED ANTLION OPTIMIZATION ALGORITHM

Initially, the ALO metaheuristic algorithm is used to calculate the optimal voltage deviation and loss minimization. ALO is based on the hunting style of antlions. On IEEE30 test systems, an evaluation of the ALO algorithm is assessed. A MALO is created and tested on IEEE30 bus test equipment in a subsequent study. To reduce loss and have a lower voltage variation, an addition to the ALO is merely the least mean square approximation. An evaluation of the ALO and MALO algorithms is conducted in comparison with other evolutionary algorithms. In terms of position updates, in this case $X_i^{t+1} = (X_i^t)^2$ is used where $X_i^t = \frac{(X_i^t - a_i)(d_i^t - c_i^t)}{b_i - a_i} + c_i^t$. The antlion optimizer algorithm will be modified in the manner described:

a. Information about systems, buses, lines, and units is read;
b. It is best to establish the MALO settings, search agents, dimension, location, and iterations at the beginning;
c. In the first population of ants and antlions, an ant and an antlion are initialized using X(t)=[0;cumsu(2r(t1)—1);cumsu(2r(t2)—1);...;cumsu(2r(tn)—1)] as a random walk followed by fitness value calculation;
d. MATLAB (each ant represents a solution) is used to calculate power lossesand voltage deviations;
e. Despite the best antlions, the end criteria is not reached, for i=1: $n_{br}$of ants;
f. A Roulette wheel is used to select the antlions and equations $c^t = \frac{c^t}{I}$, $d^t = \frac{d^t}{I}$ are used to update the parameters c and d;
g. Calculate the normalized random walks using $X_i^{t+1} = (X_i^t)^2$;
h. $Ant_j^t = \frac{R_A^t + R_E^t}{2}$ can be used to update the ant 's current locations;
i. Calculating the fitness value for each solution and verifying the variable boundaries;
j. In cases where an antlion is superior to an elite, replace the elite with antlion.

5. RESULTS AND DISCUSSION

To validate the robustness of the proposed algorithm in handling the IEEE30-bus system, a series of tests were conducted. The power system underwent 10 independent runs to identify the optimal solution. The simulation was performed on the MATLAB platform, specifically version 7.10. The research utilized a personal computer equipped with a 1.80 GHz Core (TM i3) CPU and 4GB of memory. To minimize the number of control variables and consequently the voltage deviation and real power losses, a focused approach was adopted. In studying the ORPD problem, the power loss and voltage variations were considered as a single objective fitness function. Table 2 shows a performance analysis of the IEEE 30 test bus example without any FACTS devices for power loss minimization and voltage variation. This table provides detailed insights into the power flow analysis of the IEEE 30 bus system, highlighting a voltage deviation range of approximately 0.11936 p.u and the best-fit power loss of 4.1428 MW.

For the IEEE 30 test bus case with STATCOM, UPFC, and IPFC FACTS devices, Table 3 shows the performance study of power loss minimization. This table illustrates the power loss minimization in an IEEE 30 bus system with the considered FACTS devices, and the fitness function is optimized to 3.5821 MW, 2.9191 MW, and 3.8033 MW with STATCOM, UPFC, and IPFC, respectively.

Table 2. Provides a comparative study of the IEEE 30 bus network, considering 19 decision variables and excluding FACTS devices and the MALO algorithm

Control variable	Proposed MALO with PLoss targeted fitness function	Proposed MALO with voltage deviation targeted fitness function
V_1	1.1000	0.9980
V_2	1.0952	0.9885
V_5	1.0747	1.0171
V_8	1.0825	1.0156
V_{11}	1.1000	1.0495
V_{13}	1.1000	1.0444
T_{6-9}	0.9859	1.0194
T_{6-10}	1.0500	0.9055
T_{4-12}	1.0250	1.0278
T_{27-28}	1.0055	0.9543
Qc_{10}	4.9242	1.2881
Qc_{12}	3.7574	0.9755
Qc_{15}	3.6568	0.9459
Qc_{17}	4.7737	0.0117
Qc_{20}	3.5424	4.7066
Qc_{21}	4.8584	0.7007
Qc_{23}	0.4437	3.4206
Qc_{24}	4.7621	3.9141
Qc_{29}	3.3655	1.3718
Ploss (MW)	4.1428	---
Voltage deviation	---	0.11936

Table 3. Illustrates a comparative study of the IEEE 30 bus network, focusing on power loss minimization, with 19-21 decision variables incorporating FACTS devices and the MALO algorithm

Control variable	Proposed MALO		
	STATCOM	UPFC	IPFC
V_1	1.1000	1.1000	1.1000
V_2	1.0929	1.0972	1.0810
V_5	1.0710	1.0838	1.0827
V_8	1.0933	1.0883	1.0845
V_{11}	1.1000	1.0988	1.0976
V_{13}	1.1000	1.1000	1.0920
T_{6-9}	1.0018	0.9877	1.0198
T_{6-10}	0.9493	1.0066	1.0061
T_{4-12}	0.9869	0.9967	1.0067
T_{27-28}	0.9698	0.9940	0.9998
Qc_{10}	2.2240	4.2603	3.4117
Qc_{12}	1.2655	3.2718	4.0605
Qc_{15}	4.9999	3.0427	1.3846
Qc_{17}	0.7297	2.2760	4.7899
Qc_{20}	4.9484	4.9678	4.9969
Qc_{21}	4.9981	4.5234	4.9598
Qc_{23}	4.4225	4.9479	4.9957
Qc_{24}	3.7343	4.9865	4.9993
Qc_{29}	0.9314	4.9938	2.3672
Location	23	23-24	4-12,4-3
Performance	2.8250	4.493956	1.395481
PLoss (MW)	3.5821	2.9191	3.8033

Table 4 shows the voltage deviation performance analysis for the STATCOM, UPFC, and IPFC devices in the IEEE 30 test bus case. This table illustrates the voltage deviation minimization in IEEE 30 bus system with the considered FACTS devices and the fitness function is optimized to 0.0791 p.u, 0.076 p.u, and 0.0852 p.u with STATCOM, UPFC, and IPFC respectively.

Figure 4 shows the convergence curve of power loss for an IEEE30 bus system. The effects of FACTS devices on power loss minimization are highlighted in this figure, which offers insightful comparisons of the system ‘s performance with and without FACTS devices. Figure 5 shows the convergence of voltage deviation for the same IEEE 30 bus system, The effects of FACTS devices on voltage deviation are highlighted in this figure, which offers insightful comparisons of the system ‘s performance with and without FACTS devices. The performance of each FACTS device with a normal case is compared, illustrated, and presented, and it can be inferred from the aforementioned tables and figures that power loss minimization and voltage deviation are each targeted individually as single objective functions.

Table 4. A comparison of the IEEE 30 bus network ‘s 19 decision variables, FACTS devices, and intended voltage deviation

Control variable	Proposed MALO		
	STATCOM	UPFC	IPFC
V_1	1.0002	1.0000	1.0031
V_2	1.0394	1.0428	1.0600
V_5	1.0301	1.0600	1.0423
V_8	1.0370	1.0800	1.0192
V_{11}	0.9600	0.9715	1.0020
V_{13}	0.9723	0.9657	0.9602
T_{6-9}	0.9638	0.9847	0.9654
T_{6-10}	0.9431	0.9400	0.9572
T_{4-12}	0.9672	0.9476	0.9475
T_{27-28}	0.9687	0.9637	0.9573
Qc_{10}	3.3181	1.4674	4.6009
Qc_{12}	4.1304	3.9016	0.0501
Qc_{15}	1.8337	0.0307	4.9633
Qc_{17}	1.8256	1.1998	3.4948
Qc_{20}	2.5740	3.5248	4.9941
Qc_{21}	4.8418	2.7334	0.4535
Qc_{23}	0.4248	1.0130	4.7998
Qc_{24}	4.2409	4.8859	2.5170
Qc_{29}	4.7720	3.4731	3.1252
location	18	18-19	12-16,12-15
Performance	7.357797	4.408692	2.416259
Voltage deviation	0.0791	0.076	0.0852

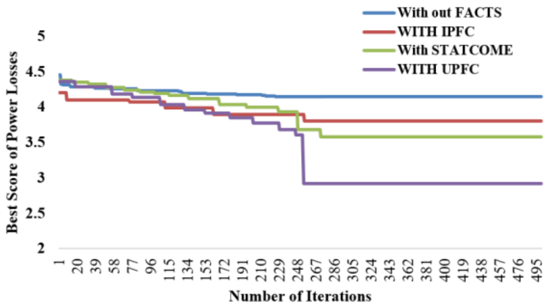

Figure 4. Learning curves for test case using MALO for line loss minimization of IEEE 30 bus system

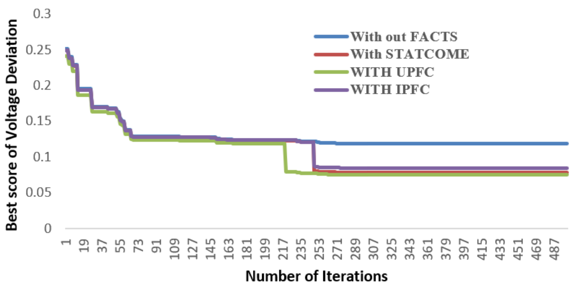

Figure 5. Learning curves for test case using MALO for voltage deviation minimization of an IEEE30 bus system

6. CONCLUSION

To address the ORPD issue in power systems utilizing STATCOM, UPFC, and IPFC FACTS devices, a MALO has been created. In the typical IEEE-30 bus system, the MALO algorithm was investigated for reducing active power losses and voltage deviation. It is compared whether MALO schemes are used with STATCOM, UPFC, or IPFC to obtain the same results. Using FACTS devices, MALO performed well with all ORPD objectives. Statistical analysis of the ORPD problems solved in standard test systems and supported the validation of the MALO. Without FACTS devices, the results show that the best-fit power loss is 4.1428 MW and the voltage deviation is about 0.11936 p.u. Power loss minimization in IEEE 30 bus system with the considered FACTS devices and the fitness function is optimized to 3.5821 MW, 2.9191 MW, and 3.8033 MW with STATCOM, UPFC, and IPFC respectively. Similarly, the fitness function is optimized to 0.0791 p.u, 0.076 p.u, and 0.0852 p.u with STATCOM, UPFC, and IPFC for the IEEE 30 bus system ‘s voltage deviation minimization using the examined FACTS devices. According to these findings, positioning UPFC produces superior outcomes in comparison to other devices.

REFERENCES

[1] T. Ding, R. Bo, Z. Bie, and X. Wang, “Optimal selection of phase shifting transformer adjustment in optimal power flow,” *IEEE Transactions on Power Systems*, vol. 32, no. 3, pp. 2464–2465, May 2017, doi: 10.1109/TPWRS.2016.2600098.
[2] L. C. da Costa, F. S. Thome, J. D. Garcia, and M. V. F. Pereira, “Reliability-constrained power system expansion planning: a stochastic risk-averse optimization approach,” *IEEE Transactions on Power Systems*, vol. 36, no. 1, pp. 97–106, Jan. 2021, doi: 10.1109/TPWRS.2020.3007974.
[3] A. M. Tudose, I. I. Picioroaga, D. O. Sidea, and C. Bulac, “Solving single-and multi-objective optimal reactive power dispatch problems using an improved salp swarm algorithm,” *Energies*, vol. 14, no. 5, 2021, doi: 10.3390/en14051222.
[4] Y. Muhammad, R. Akhtar, R. Khan, F. Ullah, M. A. Z. Raja, and J. A. T. Machado, “Design of fractional evolutionary processing for reactive power planning with FACTS devices,” *Scientific Reports*, vol. 11, no. 1, Jan. 2021, doi: 10.1038/s41598-020-79838-2.
[5] M. B. Shafik, H. Chen, G. I. Rashed, and R. A. El-Sehiemy, “Adaptive multi objective parallel seeker optimization algorithm for incorporating TCSC devices into optimal power flow framework,” *IEEE Access*, vol. 7, pp. 36934–36947, 2019, doi: 10.1109/ACCESS.2019.2905266.
[6] A. Daraz, S. A. Malik, A. T. Azar, S. Aslam, T. Alkhalifah, and F. Alturise, “Optimized fractional order integral-tilt derivative controller for frequency regulation of interconnected diverse renewable energy resources,” *IEEE Access*, vol. 10, pp. 43514–43527, 2022, doi: 10.1109/ACCESS.2022.3167811.
[7] E. Davoodi, E. Babaei, B. Mohammadi-Ivatloo, M. Shafie-Khah, and J. P. S. Catalao, “Multiobjective optimal power flow using a semidefinite programming-based model,” *IEEE Systems Journal*, vol. 15, no. 1, pp. 158–169, Mar. 2021, doi: 10.1109/JSYST.2020.2971838.
[8] A. Enshaee and G. R. Yousefi, “Tracing reactive power flows and allocating transmission lines losses: an analytical method,” *IEEE Systems Journal*, vol. 13, no. 1, pp. 783–791, Mar. 2019, doi: 10.1109/JSYST.2017.2764631.
[9] T. M. Mohan and T. Nireekshana, “A genetic algorithm for solving optimal power flow problem,” in *2019 3rd International conference on Electronics, Communication and Aerospace Technology (ICECA)*, IEEE, Jun. 2019, pp. 1438–1440, doi: 10.1109/ICECA.2019.8822090.
[10] B. Ismail, N. I. A. Wahab, M. L. Othman, M. A. M. Radzi, K. N. Vijyakumar, and M. N. M. Naain, “A comprehensive review on optimal location and sizing of reactive power compensation using hybrid-based approaches for power loss reduction, voltage stability improvement, voltage profile enhancement and loadability enhancement,” *IEEE Access*, vol. 8, pp. 222733–222765, 2020, doi: 10.1109/ACCESS.2020.3043297.
[11] M. A. Kamarposhti, H. Shokouhandeh, I. Colak, S. S. Band, and K. Eguchi, “Optimal location of FACTS devices in order to simultaneously improving transmission losses and stability margin using artificial bee colony algorithm,” *IEEE Access*, vol. 9, pp. 125920–125929, 2021, doi: 10.1109/ACCESS.2021.3108687.
[12] S. Mugemanyi, Z. Qu, F. X. Rugema, Y. Dong, C. Bananeza, and L. Wang, “Optimal reactive power dispatch using chaotic bat algorithm,” *IEEE Access*, vol. 8, pp. 65830–65867, 2020, doi: 10.1109/ACCESS.2020.2982988.
[13] P. Ramkee, S. N. V. S. K. Chaitanya, B. V. Rao, and R. A. Bakkiyaraj, “Optimal reactive power dispatch under load uncertainty incorporating solar power using firefly algorithm,” *Lecture Notes in Electrical Engineering*, vol. 766, pp. 423–434, 2022, doi: 10.1007/978-981-16-1476-7_39.
[14] R. DasMahapatra, “Optimal power control for cognitive radio in spectrum distribution using ANFIS,” in *2015 IEEE International Conference on Signal Processing, Informatics, Communication and Energy Systems (SPICES)*, IEEE, Feb. 2015, pp. 1–5, doi: 10.1109/SPICES.2015.7091360.
[15] L. Kumar, S. Kumar, S. K. Gupta, and B. K. Raw, “Optimal location of FACTS devices for loadability enhancement using gravitational search algorithm,” in *2019 IEEE 5th International Conference for Convergence in Technology (I2CT)*, IEEE, Mar. 2019, pp. 1–5, doi: 10.1109/I2CT45611.2019.9033561.
[16] B. Bhattacharyya and S. Raj, “Swarm intelligence-based algorithms for reactive power planning with Flexible AC transmission system devices,” *International Journal of Electrical Power and Energy Systems*, vol. 78, pp. 158–164, 2016, doi: 10.1016/j.ijepes.2015.11.086.
[17] S. M. Shareef and R. S. Rao, “Optimal reactive power dispatch under unbalanced conditions using hybrid swarm intelligence,” *Computers and Electrical Engineering*, vol. 69, pp. 183–193, 2018, doi: 10.1016/j.compeleceng.2018.05.011.
[18] W. S. Sakr, R. A. El-Sehiemy, and A. M. Azmy, “Adaptive diferential evolution algorithm for efcient reactive power management,” *Applied Soft Computing*, vol. 53, pp. 336–351, 2017.
[19] T. P. Naidu, G. Balasubramanian, and B. V. Rao, “Optimal power flow with distributed energy sources using whale optimization algorithm,” *International Journal of Electrical and Computer Engineering*, vol. 13, no. 5, pp. 4835–4844, 2023, doi: 10.11591/ijece.v13i5.pp4835-4844.
[20] J. Sandhiya, C. Nayanatara, and J. Baskaran, “Optimal location of UPFC for congestion relief in power systems using simulated annealing algorithm,” in *2016 International Conference on Computation of Power, Energy, Information and Communication, ICCPEIC 2016*, 2016, pp. 648–658, doi: 10.1109/ICCPEIC.2016.7557305.
[21] P. Kar, “Optimal allocation of SSSC for power oscillations damping using fire-fly algorithm,” in *Proceedings of the International Conference on Intelligent Sustainable Systems, ICISS 2017*, 2018, pp. 706–709, doi: 10.1109/ISS1.2017.8389264.
[22] M. Mahdavi, A. Kimiyaghalam, H. H. Alhelou, M. S. Javadi, A. Ashouri, and J. P. S. Catalao, “Transmission expansion planning considering power losses, expansion of substations and uncertainty in fuel price using discrete artificial bee colony algorithm,” *IEEE Access*, vol. 9, pp. 135983–135995, 2021, doi: 10.1109/ACCESS.2021.3116802.
[23] S. Mouassa, T. Bouktir, and A. Salhi, “Ant lion optimizer for solving optimal reactive power dispatch problem in power systems,” *Engineering Science and Technology, an International Journal*, vol. 20, no. 3, pp. 885–895, Jun. 2017, doi: 10.1016/j.jestch.2017.03.006.

[24] A. Rajan, K. Jeevan, and T. Malakar, "Weighted elitism-based ant lion optimizer to solve optimum VAr planning problem," *Applied Soft Computing Journal*, vol. 55, pp. 352–370, 2017, doi: 10.1016/j.asoc.2017.02.010.
[25] S. S. Shrawane, M. Diagavane, and N. Bawane, "Optimal reactive power dispatch by furnishing UPFC using multi-objective hybrid GAPSO approach for transmission loss minimisation and voltage stability," in *2015 International Conference on Nascent Technologies in the Engineering Field, ICNTE 2015-Proceedings*, 2015, doi: 10.1109/ICNTE.2015.7029923.
[26] A. Amin, S. Kamel, and M. Ebeed, "Optimal reactive power dispatch considering SSSC using Grey Wolf algorithm," in *2016 Eighteenth International Middle East Power Systems Conference (MEPCON)*, IEEE, Dec. 2016, pp. 780–785, doi: 10.1109/MEPCON.2016.7836982.
[27] S. N. V. S. K. Chaitanya, R. A. Bakkiyaraj, B. V. Rao, and K. Jayanthi, "Scenario-based method to solve optimal reactive power dispatch using modified ant lion optimizer considering uncertainties in load, solar, and wind power," *International Journal of Renewable Energy Research*, vol. 13, no. 2, pp. 579–591, 2023, doi: 10.20508/IJRER.V13I2.13864.G8727.
[28] K. M. K. Reddy, K. A. Rao, and R. S. Rao, "Optimal siting and sizing of unified power flow controller using sensitivity constrained differential evolution algorithm," *International Journal of Electrical and Computer Engineering*, vol. 12, no. 5, pp. 4680–4687, 2022, doi: 10.11591/ijece.v12i5.pp4680-4687.
[29] G. A. Salman, H. G. Abood, and M. S. Ibrahim, "Improvement the voltage stability margin of Iraqi power system using the optimal values of FACTS devices," *International Journal of Electrical and Computer Engineering*, vol. 11, no. 2, pp. 984–992, 2021, doi: 10.11591/ijece.v11i2.pp984-992.
[30] M. Vishnu and S. K. T. K., "An improved solution for reactive power dispatch problem using diversity-enhanced particle swarm optimization," *Energies*, vol. 13, no. 11, Jun. 2020, doi: 10.3390/en13112862.

BOGRAPHIES OF AUTHORS

Sela Naga Venkata Sri Krishna Chaitanya received his Bachelor degree in Electrical and Electronics Engineering from College of Engineering, DVR and Dr. HS MIC College of Technology, Kanchikacherla, Andhra Pradesh, India in 2006, and the Master degree in Power Systems Engineering from the College of Engineering, R V R and J C College of Engineering, Guntur in 2008 and pursuing Ph.D. from Annamalai University, Chidambaram, Tamil Nadu. He is presently working as Assistant Professor in the Department of Electrical and Electronics Engineering, V R Siddhartha Engineering College, Vijayawada. His research interests are optimal reactive power dispatch, FACTS devices, and renewable energy. He has published several research papers in national and international conferences and journals. He can be contacted at email: snvskchaitanya@vrsiddhartha.ac.in.

R. Ashok Bakkiyaraj was born on July 31, 1977. He completed B.E. degree in Electrical and Electronics in 1998 and M.E. degree in Power Systems in 2005 and received Ph.D. in 2014 from Annamalai University. He is presently working as Associate Professor in the Department of Electrical Engineering, Annamalai University, India. His research interests include power system reliability, power system optimization, image processing, and applications of artificial intelligence techniques in power system. He has published 15 research articles in international journals and presented research papers in 12 international/national conferences. He is the life fellow of Institution of Engineer 's (India) and life member of Indian society of Technical Education. He can be contacted at email: auashok@gmail.com.

Bathina Venkateswara Rao received his Bachelor degree in Electrical and Electronics Engineering from College of Engineering, Gandhi Institute of Technology And Management (GITAM), Visakhapatnam, India in 2000, and the Master degree in Electrical Power Engineering from the College of Engineering, JNTU, Hyderabad in 2007 and received Ph.D from Jawaharlal Nehru Technological University, Hyderabad in 2015. He is presently working as Associate Professor in the Department of Electrical and Electronics Engineering, V R Siddhartha Engineering College, Vijayawada. His research interests are power system stability analysis, FACTS devices, and power system control. He has published several research papers in national and international conferences and journals. He can be contacted at email: drbvrao@vrsiddhartha.ac.in.

Kalikrishnan Jayanthi is with Department of Computer and Information Science, Annamalai University as Assistant Professor (Deputed). She completed Master of Computer Application from Bharathidhasan University, India and M.Phil and Ph.D. (Computer science) from Annamalai University, India. She is doing research in the area of artificial intelligence algorithms for engineering optimization and image processing applications with AI. She has published 6 research articles in international journals and presented research papers in 8 international/national conferences. She can be contacted at email: jayanthirab@gmail.com.