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Real Power Minimization with Voltage Profile Enhancement Using Series and Shunt FACTS Controllers – Sine Cosine Algorithm Approach

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Abstract

Proper management of reactive power resources is essential for the secure and stable functioning of power systems in the standpoint of voltage stability. The main purpose of optimal reactive power dispatch (ORPD) is to detect the settings of control variables such as the voltage rating of generators, reactive power injection of VAR compensators and tap ratios of the tap setting transformers in order to decrease the grid congestion with one or more objective of minimizing the active power loss for a fixed economic power schedule while taking on a given set of constraints. In this paper, Flexible AC Transmission System (FACTS) controllers named as Static Var Compensator (SVC) and Thyristor Controlled Series Capacitor (TCSC) are added to the conventional ORPD problem for active power loss minimization with voltage profile improvement. As well, this report presents the application of sine cosine algorithm (SCA) to find the optimal solution of ORPD (with and without FACTS devices) of power arrangement with different examination systems (Standard IEEE 14-bus, IEEE 57-bus and IEEE 118-bus) with distinct cases such as minimization of active power losses and improvement of voltage profile. Simulation results demonstrate the high tone and accuracy of the proposed algorithm, and considering the quality of the solution obtained, the proposed algorithm appears to be efficient and robust to solve the ORPD problem (with and without FACTS devices) comparing with existing literatures.

Keywords: *Optimal reactive power dispatch, Active power Loss reduction, Improvement of voltage profile, FACTS devices, Sine cosine algorithm, Whale optimization algorithm, Ant lion optimizer*

1. Introduction

In the final few decades, optimal reactive power dispatch (ORPD) has received great attention and it has become a tool for improving the economy and security of power system performance. The ORPD, which is a non-linear, non-convex and non-differentiable optimization problem, aims at minimizing the objective functions such as voltage stability and system real power losses via adjustments of control parameters like generator voltages, switchable volt-ampere reactive (VAR) sources, transformer tap settings and so on in a power system while satisfying equality and inequality constraints [1-3].

Agreeing to the literature, mathematical algorithms such as Decomposition method, Newton approach, non-linear programming, interior point, Jacobian matrix etc. have been used for ORPD solutions initially [4-7]. These algorithms optimize the objective function by linearizing it. Since the ORPD problem has local optima more than one, it is a non-linear and multi-modal optimization problem. Hence, it is so tough to determine the global optimum using mathematical algorithms in the resolution

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of the ORPD problem. However, in that respect are some disadvantages specially to the algorithms such as insecure convergence and algorithmic complexity. For these causes, researchers were developed heuristic and meta heuristic based algorithms for solving the ORPD problem was shown in Table. 1.

Table 1: Summary of the proposed algorithms for solution of ORPD problem in literature

Reference	**Approach**	**Objective**	**Test System**
Yan et al. (2004) [8]	IEP	Power loss	IEEE 118-bus system and a realistic power system in Western China
Zhao et al. (2005) [9]	MAPSO	Power loss	IEEE 30-bus and IEEE 118-bus
Varadarajan and Swarup(2008) [10]	DE	Power loss	IEEE 14, IEEE 30, and IEEE 118-Bus
Ying Li et al. (2009) [11]	DPSO	power loss and the costs of adjusting the control devices	IEEE 30-bus
Chaohua et al. (2009) [12]	SOA	Power loss	IEEE 57-bus and IEEE 118-bus
Mahadevan and Kannan(2010) [13]	CLPSO	Power loss and voltage profile	IEEE 30-bus and IEEE 118-bus
Xuexia Zhang et al., (2010) [14]	DMSDE	Power loss	IEEE 30-bus, IEEE 57-bus and IEEE 118-bus
Khazali and Kalantar (2011) [15]	HSA	Power loss and voltage profile	IEEE 30-bus and IEEE 57-bus
S. Jeyadevi et al. (2011) [16]	MNSGA-II	Power loss and voltage stability	IEEE 30-bus and IEEE 118-bus
Roy et al. (2012) [17]	BBO	Power loss and voltage profile	IEEE 30-bus and IEEE 118-bus
Xu et al. (2012) [18]	MASRL	Power loss	Ward-Hale 6-bus, IEEE 30-bus and IEEE 162-bus
S. Duman et al. (2012) [19]	GSA	Power loss, voltage profile, and voltage stability	IEEE 30-bus, IEEE 57-bus and IEEE 118-bus
R. Mallipeddi et al. (2012) [20]	HDE	Power loss and voltage profile	IEEE 30-bus, IEEE57-bus and IEEE 118-bus
Barun Mandal and Provas Kumar Roy (2013) [21]	QOTLBO	Power loss, voltage profile, and voltage stability	IEEE 30-bus and IEEE 118-bus
Amit Saraswat and AshishSaini (2013) [22]	HFMOEA	Power loss and voltage stability	IEEE24-busRTS
Mojtaba Ghasemi et al. (2014) [23]	HMICA-IWO	Power loss	IEEE 30-bus, IEEE 57-bus and IEEE 118-bus
Binod Shaw et al. (2014) [24]	OGSA	Power loss, voltage profile, and voltage stability	IEEE 30-bus, IEEE 57-bus and IEEE 118-bus
Abhishek Rajan and T. Malakar (2015) [25]	HFA	Power loss and voltage deviation	IEEE 30-bus and IEEE 118-bus
Mojtaba Ghasemi et al. (2015) [26]	MGBTLBO	Power loss	IEEE 14-bus and IEEE30-bus
Mehdi Mehdinejad et al. (2016) [27]	ICA-PSO	Power loss and voltage deviation	IEEE57-bus and IEEE 118-bus
kuppamuthu sivalingam et al. (2017) [28]	HABC	Power loss	IEEE 6-bus, IEEE14-bus, and IEEE 30-bus
Kasem Nuaekaew et al. (2017) [29]	2ArchMGWO	Power loss and voltage profile	IEEE 30-bus, IEEE 57-bus and IEEE 118-bus
Xiaoshun Zhang et al. (2017) [30]	ABO-TRL	Power loss and voltage deviation	IEEE118-bus and IEEE 300-bus
Khaled ben oualid Medania (2018) [31]	WOA	Power loss	IEEE 14-bus, IEEE 30-bus, Algerian electric 114-bus
SK. Mahammad Shareefa and R. Srinivasa Rao (2018) [32]	ABC-FF	Power loss and voltage stability	IEEE 14 and IEEE 39 bus
Hotaka yoshida and Yoshikazu fukuyama (2018) [33]	DEEPSO	Power loss	IEEE 30-bus, IEEE 57-bus and IEEE 118-bus

Recently, Sine, Cosine Algorithm (SCA) has been a new meta-heuristic search algorithm. It has been proposed by Seyedali Mirjalili in 2016. It has been described in [34] that the SCA holds a mass of advantages and it is different from the other meta heuristic algorithms like GSA etc. These are shown in

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detail in [34]. Moreover, in [34], SCA has been tested on 19 different standard benchmark functions and aircraft design problem compared with other meta heuristic algorithms such as the Firefly Algorithm (FA), Bat Algorithm (BA), Flower Pollination Algorithm (FPA) and Gravitational Search Algorithm (GSA).

It was found that the effects received by SCA in most cases provide superior results and in all cases are comparable with others. The most significant feature of the SCA is that creating multiple initial random candidate solutions and calls for them to fluctuate outwards or towards the best result utilizing a mathematical model based on sine and cosine functions. Several random and adaptive variables also are integrated to this algorithm to emphasize exploration and exploitation of the search space in different milestones of optimization.

For all these grounds, in this paper SCA is chosen in order to solve the ORPD problem in addition with FACTS devices. Two types of FACTS devices, Static Var Compensator (SVC) and Thyristor Controlled Series Capacitor (TCSC) are taken with the conventional ORPD problem. The primary reason for SVC is to absorb or generate reactive power depends upon the requirement of the reactive power in the system to improve the electric potential profile and trim back the system losses. Also, TCSC provides continuous control of active power of the line with variable series capacitance. Along with the conventional variables, the location and sizing as well considered as the variables in the optimization problem. In order to evaluate the proposed algorithm, it was tested on IEEE 14-bus, 57-bus and 118-bus test systems with different objective functions that reflect active power losses and voltage profile improvement, and results obtained from SCA are compared with those reported in the literature.

Power Flow Model for FACTS Devices

FACTS devices are the power electronics based solid state converters that can be integrated in power system as shunt and series connected devices. The series controllers build up voltage in series with the line and the shunt controllers injects current into the system. The combined series and shunt controllers inject both voltage and current into the system. Shunt compensation are used to supply reactive power compensation and series compensator is used to heighten the power flow [35-38]. Two types of FACTS devices, namely static VAr compensators (SVC) and thyristor controlled series capacitors (TCSC) are employed in the transmission network:

- The SVC can be run as either inductive or capacitive compensation. It can be modeled as a fixed condenser and a thyristor-controlled reactor. Thus the part of the SVC is either to inject reactive power to the coach or to absorb reactive power from the bus where it is plugged in.
- TCSC: By modifying the line reactance TCSC acts as either inductive or capacitive compensator. The maximum value of the capacitance is fixed at $-0.8X_{Line}$ and $0.2X_{Line}$ is the maximum value of the inductance.

A. Modeling of SVC

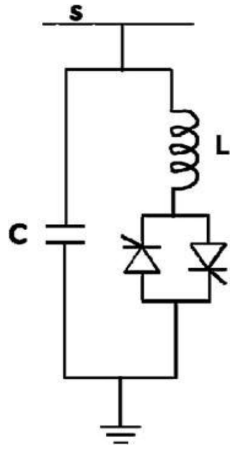

Figure 1: SVC model

The schematic diagram of SVC device is illustrated in Fig. 1. It consists of fixed capacitor and thyristor-controlled reactor. The equivalent susceptance Beq, which neglects harmonic current, can be expressed as

$$B_{eq} = B_L(\propto) + B_C \tag{1}$$

Where,

$$B_L(\propto) = -\frac{1}{\omega L}\left(1 - \frac{2\alpha}{\pi}\right) and\ B_C = \omega \times C$$

The SVC is shunt connected static VAR generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of electrical power system, typically a bus voltage. The reactive power provided by SVC in the power flow framework can be expressed equally

$$Q_{SVC} = -V_k^2 \times B_{SVC} \tag{2}$$

B. Modeling of TCSC

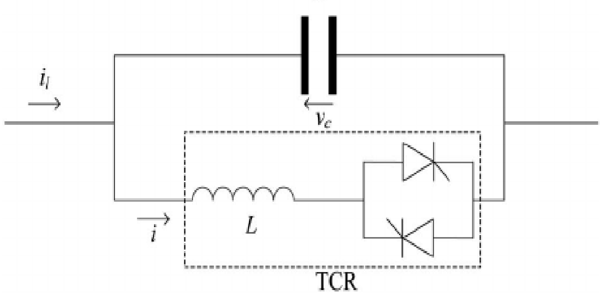

Figure 2: TCSC model

Fig. 2 presents the general circuit structure of TCSC. It consists of a series capacitor in parallel with a thyristor-controlled reactor (TCR). TCR is a variable reactor X_L controlled by firing angle (α). The effective reactance of TCSC may be represented as follows:

$$X_{TCSC}(\alpha) = \frac{X_C X_L(\alpha)}{X_L(\alpha) - X_C} = -jX_C \quad (3)$$

2. Problem Formulation

The solution of the optimal reactive power dispatch (ORPD) problem involves the optimization of the non-linear objective function with non-linear system constraints.

2.1. Minimization of real power losses

The main objective of multi objective optimization is to minimize the active power loss in the transmission network, which is set as follows [8-34]:

$$F_1 = \sum_{k=1}^{NT} P_{loss,k} = \sum_{k=1}^{NT} G_k \left(V_i^2 + V_j^2\right) - 2V_iV_j \cos\left(\delta_i - \delta_j\right) \quad (4)$$

Where NT is the number of transmission lines, G_k is the conductance of the k^{th} line, V_i and V_j are the voltage magnitude of the i^{th} and j^{th} buses, and δ_i and δ_j are the voltage phase angles of i^{th} and j^{th} buses.

2.2. Improvement of voltage profile

Another objective of this problem is to improve the voltage profile which is formulated mathematically as follows [13,17,19-21,24,29],

$$F_2 = \sum_{i=1}^{NPQ} \left|V_{i,spec} - V_i\right| \quad (5)$$

Where NPQ is the number of load buses in the power system and Vi is the reference value of the voltage magnitude of the i^{th} bus which is equal to 1.0 (pu)
By combining the Eq.(4) and Eq. (5) leads to the main objective function as follows:

$$F_{obj} = F_1 + F_2 = \left(\sum_{k=1}^{NT} P_{loss,k}\right) + \left(\sum_{i=1}^{NPQ} \left|V_{i,spec} - V_i\right|\right) \quad (6)$$

2.3. Constraints

2.3.1. Equality constraints

These constraints, which are load flow equations, are described as follows

$$P_{Gi} - P_{Di} - \sum_{j\in NB} V_iV_j(G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij}) = 0 \quad (7)$$

$$Q_{Gi} - Q_{Di} - \sum_{j\in NB} V_iV_j(G_{ij}\sin\delta_{ij} + B_{ij}\cos\delta_{ij}) = 0 \quad (8)$$

Where NB is the number of buses, P_{Gi} and Q_{Gi} are generated active and reactive power, P_{Di} and Q_{Di} are load active and reactive power, G_{ij} is the transfer conductance and B_{ij} is the transfer susceptance between i^{th} bus and j^{th} bus, respectively.

2.3.2. Inequality constraints

2.3.2.1. Generator constraints

Generator voltages, reactive outputs ought to be limited by their lower and upper limits as follows

$$Q_{G,i}^{\min} \le Q_{G,i} \le Q_{G,i}^{\max} \qquad i \in NG$$
(9)

$$V_{G,i}^{\min} \le V_{G,i} \le V_{G,i}^{\max} \qquad i \in NG$$
(10)

2.3.2.2. Transformer constraints

Transformer tap setting are bounded as follows:

$$T_i^{\min} \le T_i \le T_i^{\max} \qquad i \in No.of\ \ transformers$$
(11)

2.3.2.3. Shunt VAr compensator constraints

Shunt VAR compensators ought to be restricted by their lower and upper limits as follows

$$Q_{C,i}^{\min} \le Q_{C,i} \le Q_{C,i}^{\max} \qquad i \in NC$$
(12)

2.3.2.4. Security constraints

These include the constraints of voltages at load buses and transmission line loading as follows:

$$V_{L,i}^{\min} \le V_{L,i} \le V_{L,i}^{\max} \qquad i \in NPQ$$
(13)

$$S_{L,i} \le S_{L,i}^{\max} \qquad i \in NT$$
(14)

2.3.2.5. SVC constraints

$$Q_{svc(s),\min} \le Q_{svc(s)} \le Q_{svc(s),\max} \quad where \quad (s) \in NSVC$$
(15)

Where $Q_{SVC(s)}$ is the VAR rating of SVC and $Q_{SVC(s),min}$ and $Q_{SVC(s),max}$ are the minimum and maximum VAr limits of SVC. NSVC is the number of nodes having SVC. *(s)* represents the current SVC bus number under consideration.

2.3.2.6. TCSC var constraints

$$-0.7X_{L,TCSC} \le X_{TCSC(s)} \le 0.2X_{L,TCSC} \quad where \quad (s) \in NTCSC$$
(16)

where $X_{L,TCSC}$ is the reactance of the line, where TCSC is connected. $X_{TCSC(s)}$ is the reactance of the s^{th} TCSC. NTCSC is the number of lines having TCSC. *(s)*represents the current TCSC line number under consideration.

Eq. (4) and Eq. (5) are changed to the following form using penalty terms to the objective function:

$$F_{new} = F_{obj} + \lambda_V \sum_{i=1}^{NPQ}\left(V_i - V_i^{\lim}\right)^2 + \lambda_Q \sum_{i=1}^{NG}\left(Q_{G,i} - Q_{G,i}^{\lim}\right)^2$$
(17)

$x^{\lim}$ is the limit value of the dependent variable x = (V_i and Q_G) and given as:
$x^{\lim} = x^{\max}$ if $x > x^{\max}$, and $x^{\lim} = x^{\min}$ if $x < x^{\min}$
Where $\lambda_V$and λ_Q are the weighting factors to enhance the objective function.

Sine Cosine Optimization Algorithm

Regardless of the differences between algorithms in the field of stochastic population-based optimization, the green is the divergence of the optimization process into two phases: exploration versus exploitation. In the former phase, an optimization algorithm combines the random solutions in the set of solutions abruptly with a high rate of randomness to find the shining parts of the search space. In the development phase, all the same, there are gradual changes in the random solutions, and random variations are considerably less than those in the exploration stage.

In this SCA [35], the following position updating equations is proposed for both phases:

$$X_i^{t+1} = X_i^t + r_1 \times sin(r_2) \times \|r_3 P_i^t - X_i^t\| \quad (18)$$

$$X_i^{t+1} = X_i^t + r_1 \times cos(r_2) \times \|r_3 P_i^t - X_i^t\| \quad (19)$$

where X_i^t is the position of the current solution in i^{-th} dimension at t^{-th} iteration, $r_1/r_2/r_3$ are random numbers, $P_i$is position of the destination point in i^{-th} dimension, and || indicates the absolute value.

By combining the Eq. (18) and Eq. (19), it will be used as,

$$X_i^{t+1} = \begin{cases} X_i^t + r_1 \times sin(r_2) \times \|r_3 P_i^t - X_i^t\| r_4 < 0.5 \\ X_i^t + r_1 \times cos(r_2) \times \|r_3 P_i^t - X_i^t\| r_4 \geq 0.5 \end{cases} \quad (20)$$

wherer_4 is a random number in [0,1].

From the Eq. (18), there are four main parameters in the SCA: r_1,r_2,r_3 and r_4.

- The parameter r_1 dictates the next position's region (or motion direction) which could be either in the space between the solution and destination or outside it.
- The parameter r_2 defines how far the trend should be towards or outwards the destination.
- The parameter r_3 brings a random weight for the destination in order to stochastically emphasize (r_3> 1) or deem- phases (r_3< 1) the effect of destination in defining the space.
- Lastly, the parameter r4 equally switches between the sin and cosine components in Eq. (17).

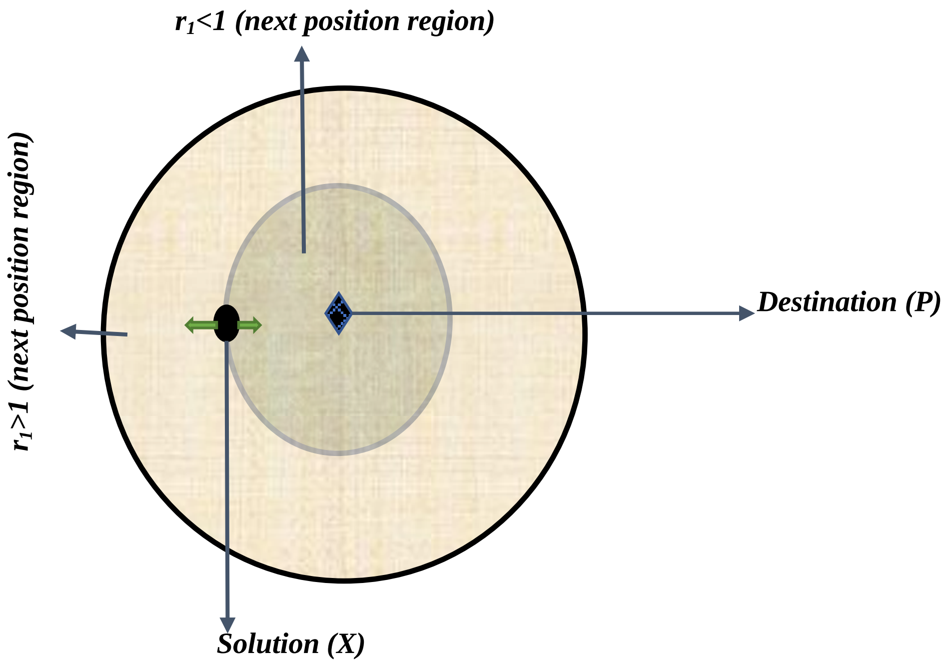

Figure 3: Properties of Sine and Cosine on the side by side post

The effects of Sine and Cosine on Eqs. (18) and(19) are illustrated in Fig. 3. This number shows that how the proposed equations define, a space between two solutions in the search blank. It should be noted that this equivalence can be stretched to higher dimensions, although a two-dimensional example is illustrated in Fig. 3. The cyclic pattern of sin and cosine function allows a solution to be re-positioned around another solution. This can guarantee exploitation of the space defined between two solutions. For researching the search space, the solutions should be capable to seek outside the space between their corresponding destinations as well. This can be achieved by changing the sphere of the sin and cosine functions. A conceptual model of the effects of the sine and cosine functions with the range in [-2, 2] is illustrated in the Fig. 4. This copy establishes how fluctuating the range of sine and cosine functions requires a solution to update its position out of entries or in the space between itself and another solution. The random location either at the rear or outside is achieved by assigning a random number for r2 in [0, 2π] in Eq. (20). Therefore, this mechanism guarantees exploration and exploitation of the search space respectively.

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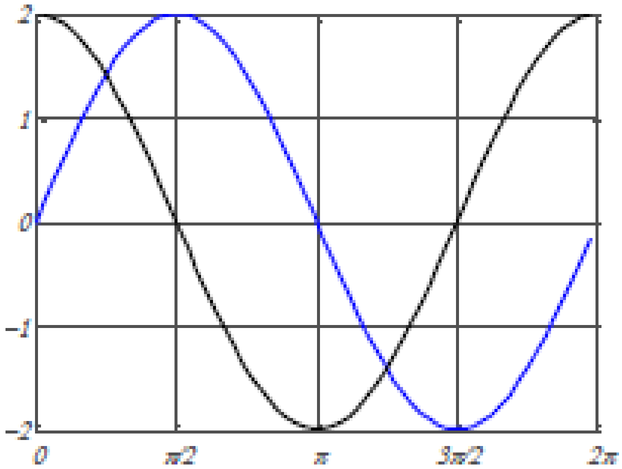

Figure 4: Sine and cosine with range of [-2,2]

The following equation is used to update the value of r_1 in Eqs. (15) to (17),

$$r_1 = a - t\frac{a}{T} \quad (18)$$

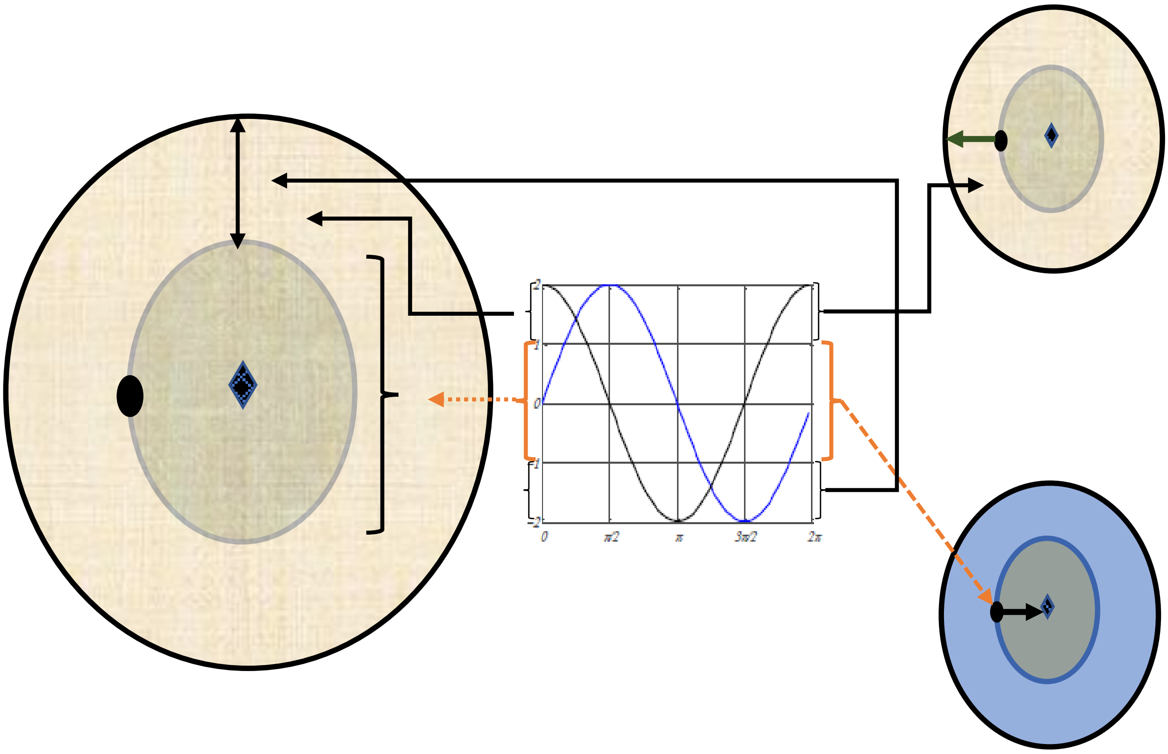

Figure 5: Sine and cosine with the range in [-2,2] allow a solution to go around (inside the space between them) or beyond (outside the space between them) the destination

Where t is the current iteration, T is the maximum number of iterations, and a is a constant.

From the explanation, equation decreases the range of sine and cosine functions over the course of iterations are shown in Fig. 5.

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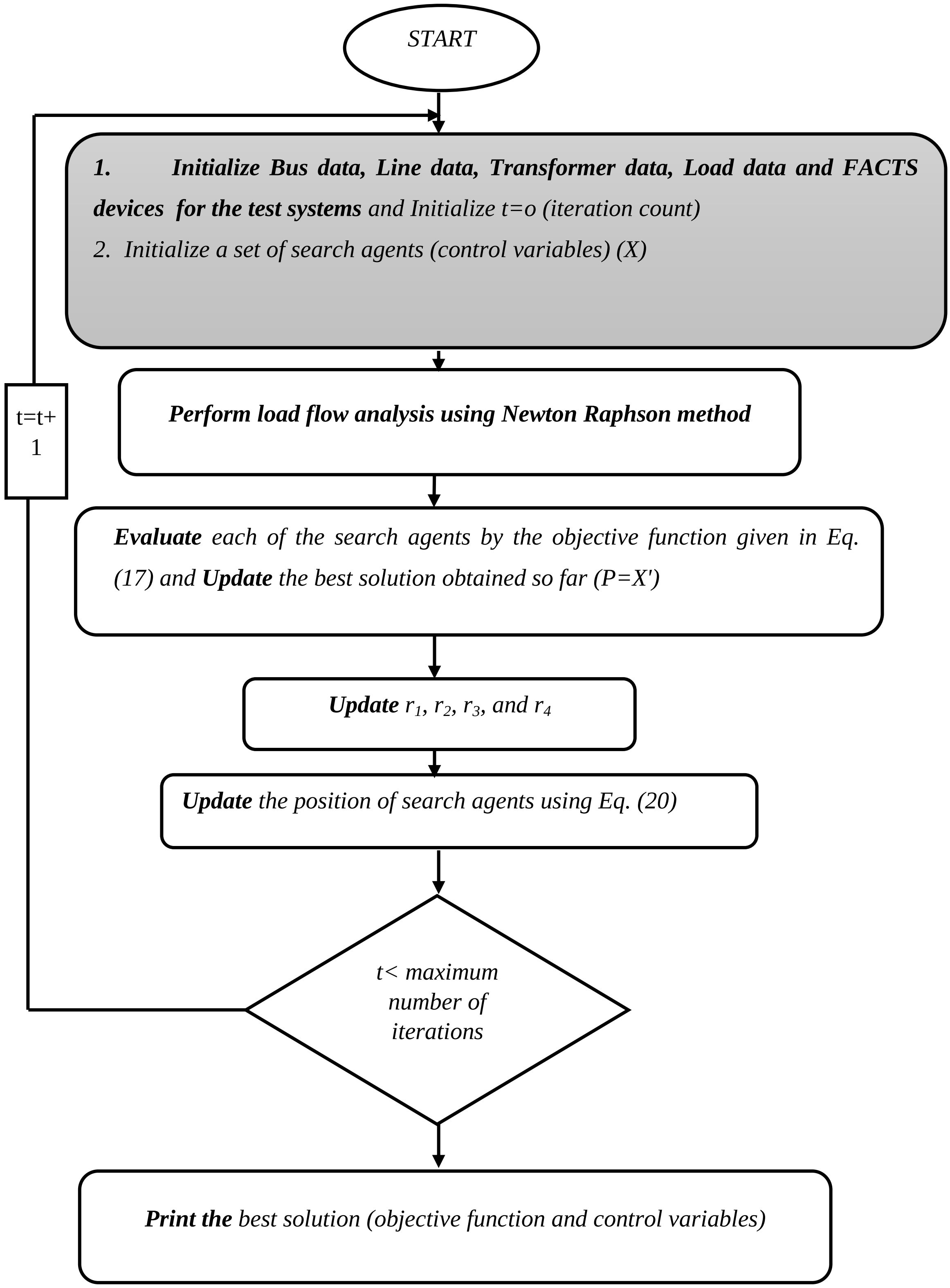

Figure 6: Flowchart for the solution of the SCA Algorithm for ORPD problem

2.4. Implementation of Sine Cosine Optimization Algorithm for ORPD with FACTS devices

Step1: Initialization the set of search agents (control variables) (X).

$$X^T = \left[V_{G1} ... V_{GNPV}, Q_{C1} .... Q_{CNC}, T_1 ... T_{NT}, Q_{svc(1)} ... Q_{svc(NSVC)}, X_{TCSC(1)} ... X_{TCSC(NTCSC)}\right]$$

Step 2: Perform Newton Raphson load flow analysis, and ascertain the solution using Eq. (17) for the initialized set of search agents from step 1.

Step 3: Save the best solutions obtained so far, assigns it as the last point (P=X'), and update the other solutions with respect to it.

Step 4: Meanwhile, the ranges of sine and cosine functions (r_1, r_2, r_3, and r_4) are updated to emphasize development of the search space as the iteration counter increases

Step 5: Check the termination criteria (In this study, SCA algorithm terminates the optimization process when the iteration counter goes higher than the upper limit number of iterations by default). If it is satisfied, publish the best solution (objective function and control variables) else Update the position of search agents using Eq. (20) and go to step 2.

Test Systems

In this paper, sine cosine algorithm is applied to standard IEEE 14, IEEE 57 and IEEE 118 test systems for the solution of the conventional ORPD problem. 25 Trial runs were also taken for each of the process and the best results of each process are presented for comparison. The maximum number of iterations was taken 1000, for each case. Single line diagram of all the test systems were given in Fig. 7, 8 and Fig. 9 with its description is depicted in Table 2. Simulations are carried out using *MATlab* R2015a software [39]. All the necessary details about the test systems were taken from MATPOWER tool box [40].

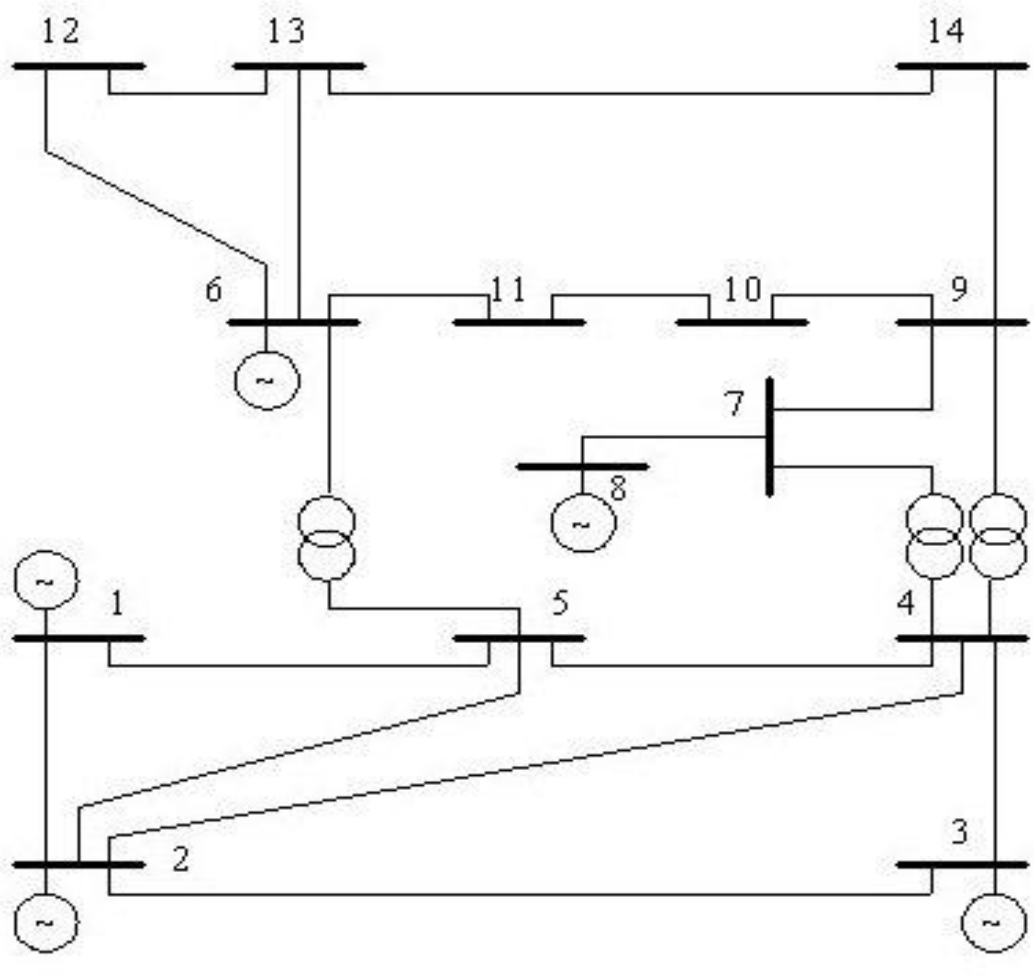

Figure7: Single line diagram of IEEE-14 bus system

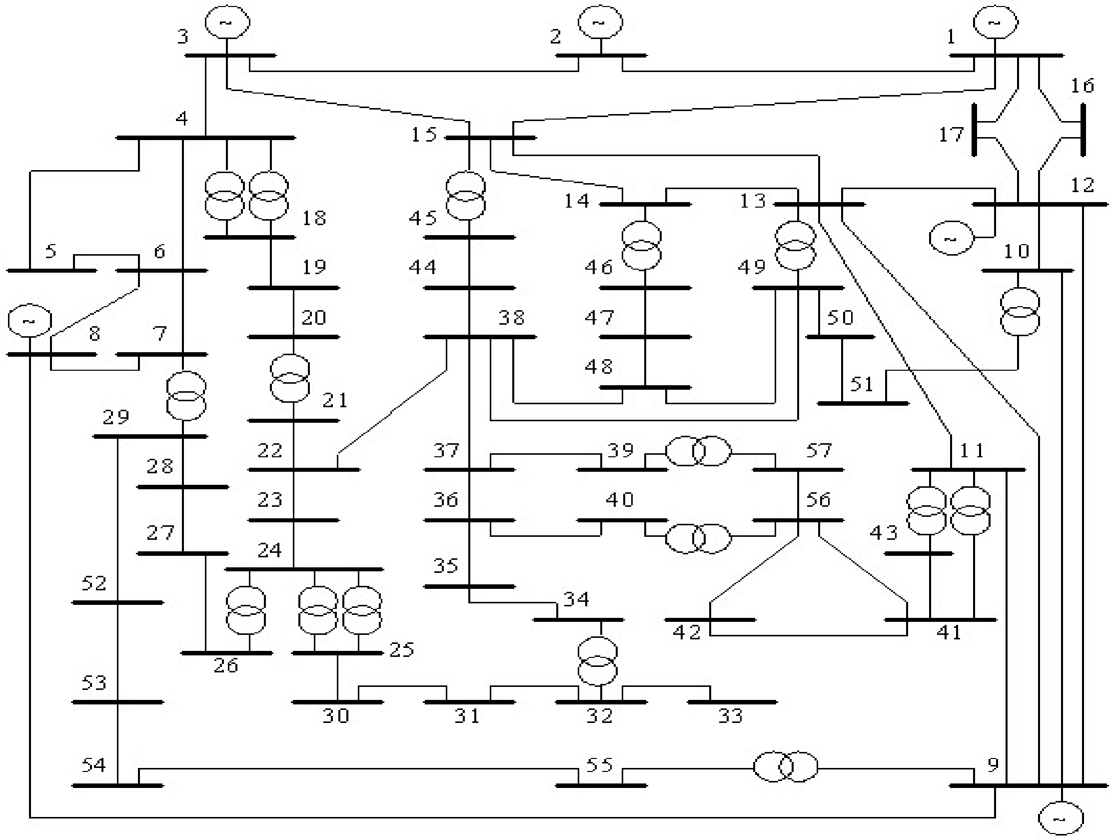

Figure 8: Single line diagram of IEEE-57 bus system

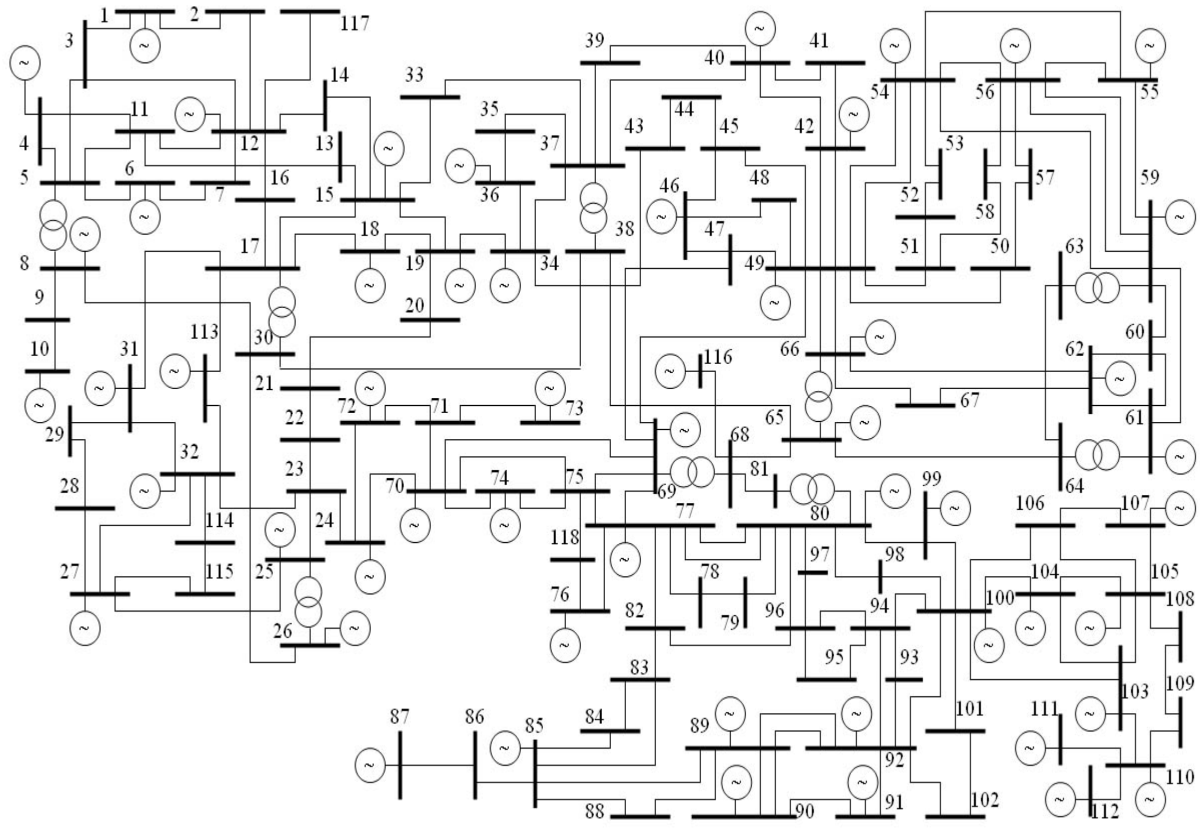

Figure 9: Single line diagram of IEEE-118 bus system

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Table 2: Description of test systems – Base case

Description	IEEE 14-bus	IEEE 57-bus	IEEE 118-bus
Buses	14	57	118
Generators	5	7	54
Transformers	3	15	9
Shunts	2	3	14
Branches	20	80	186
Control variables	10	25	77
Base case P_{Load} (MW)	259.00	1250.80	4242
Base case Q_{Load} (MVAr)	73.50	336.40	1438
Base case P_{Loss} (MW)	13.49	28.462	132.283

Results and Discussion

2.5. Test system 1: Standard IEEE-14 bus system

The standard IEEE 14-bus system consists of 20 transmission lines, five generators at 1, 2, 3, 6 and 8 and 15 branches under load tap setting transformer branches for 4-7, 4-9 and 5-6. The reactive power sources are considered at buses 9 and 14. The system line data, bus information, variable limits and the initial values of the control variables were presented in [40]. Initially, P_{Load} is 259 MW and Q_{Load} is 73.50 MVAr before optimization. The upper and lower limits of generation reactive power and control variable limits of test system are given in Table 3, respectively.

Table 3:Limits of control variables for IEEE 14 bus system

Generator		***Transformer***		***Reactive power sources***		***SVC***		***TCSC***	
V_G^{min}	V_G^{max}	T_i^{min}	T_i^{max}	Q_C^{min}	Q_C^{max}	Q_{SVC}^{min}	Q_{SVC}^{max}	X_{TCSC}^{min}	X_{TCSC}^{max}
0.95	1.1	0.9	1.1	-0.3	0.0	-0.3	0.3	$-0.8X_{ij}$	$0.2X_{ij}$

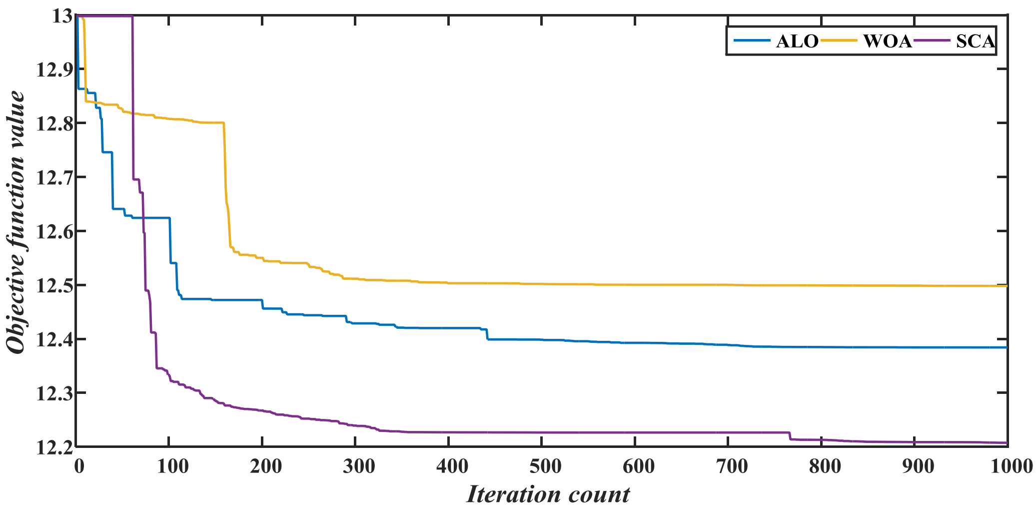

Figure10:Convergence characteristics of IEEE-14 bus system

The proposed approach is applied for minimisation of active power losses with improvement of voltage profile as the objective function. The obtained optimal values of control variables from the proposed SCA method are presented in Table 4. The obtained minimum real power loss from the proposed SCA approach is 11.9391 MW from the basecase real power loss of 13.49 MW. Fig. 10 shows the convergence characteristic of SCA for the proposed objective function. It shows that the SCA finds the better convergence compared with WOA and ALO. The results obtained from the proposed GSA method were compared with the other methods in the literature with the computational time of each algorithm are given in Table 5. It can be assured that both the power loss and the computing time of SCA is less than the other evolutionary algorithms reported in the literature.

Table 4:Best control variables settings and active power loss for IEEE 14 bus system

Optimization method	*SCA (proposed)*	*WOA (proposed)*	*ALO (proposed)*	*HSA [35]*	*IHSA [35]*
V_1,(pu)	1.0931	0.9760	1.0515	1.099	1.1
V_2,(pu)	1.0116	1.0232	0.9930	1.074	1.0931
V_3,(pu)	1.1000	1.0235	1.0177	1.0587	1.0687
V_6,(pu)	1.0865	1.1000	1.1000	1.0938	1.0954
V_8,(pu)	1.0580	1.0866	1.0753	1.0767	1.0865
T_{4-7}	1.0931	1.0589	1.0575	0.9916	0.97347
T_{4-9}	1.0972	1.1000	1.0472	0.9872	1.007
T_{5-6}	1.0594	1.0354	0.9763	0.9864	1.0526
Qc_{-9} (MVAr)	27.3476	25.5553	29.6613	25.105	28.315
Qc_{-14} (MVAr)	29.2124	25.9727	25.3325	6.1897	2.9778
Q_{svc}(MVAr)	(12) 6.6162	(3) 7.4779	(3) 20.1292	(4)10.561	(6)25.883
Q_{svc}(MVAr)	(14) 4.1548	(1) 4.2637	(8) 19.728		
Q_{svc}(MVAr)	(5) 29.2592	(5) 27.7675	(14) 22.793		
X_{TCSC} (pu)	0.02791(2-3)	0.81514 (3-4)	0.02134(2-3)	0.05148 (2-3)	0.39109 (3-4)
X_{TCSC} (pu)	0.04112(3-4)	0.05125 (7-9)	0.54321(12-6)		
X_{TCSC} (pu)	0.0132(12-6)	0.05327(10-11)	0.76543(7-9)		
P_{Loss} (MW)	***11.9391***	12.2801	12.4312	12.198	12.065

Table 5: Best solutions of all algorithms for IEEE 14 bus system

Algorithms	*Best (pu)*	*Worst (pu)*	*Mean (pu)*	*Std. deviation*	*% P_{save}*
DE [10]	0.1324	0.1328	0.1325	1.61×10^{-4}	1.86
PSO [34]	0.1325	0.1340	0.1335	0.64×10^{-3}	1.75
ACOR[34]	0.1312	0.1357	0.1339	7.1854×10^{-2}	2.72
DE/best/2/bin[34]	0.1299	0.1301	0.1309	6.5036×10^{-4}	3.7
ABC[34]	0.1293	0.1312	0.1296	9.422×10^{-4}	4.13
LCA[34]	0.1299	0.1316	0.1305	5.5283×10^{-3}	3.71
CSS[34]	0.1297	0.1330	0.1312	4.206×10^{-2}	3.82
BRCFF[34]	0.1293	0.1298	0.1293	8.8191×10^{-5}	4.18
BB-BC[34]	0.1300	0.1323	0.1311	4.7604×10^{-3}	3.6
PBIL[34]	0.1300	0.1319	0.1309	9.7075×10^{-4}	3.63
TLA[34]	0.1292	0.1295	0.1293	9.0283×10^{-5}	4.2
MTLA [34]	0.1291	0.1292	0.1292	7.6832×10^{-5}	4.3
DDE [34]	0.1293	0.1293	0.1293	5.0065×10^{-5}	4.16
MTLA-DDE[34]	0.1290	0.1290	0.1290	6.486×10^{-6}	4.39
TLBO [26]	0.1299	0.1299	0.1299	9.28×10^{-5}	3.72
BBPSO [26]	0.1299	0.1300	0.1299	9.45×10^{-5}	3.69
BBDE [26]	0.1300	0.1311	0.1300	8.62×10^{-5}	3.64
GBTLBO [26]	0.1242	0.1242	0.1242	0.75×10^{-5}	7.97
MGBTLBO [26]	0.1231	0.1236	0.1232	0.42×10^{-5}	8.74
HSA [35]	0.1281	0.1283	0.1281	5.346×10^{-6}	5.07
IHSA [35]	0.1279	0.1288	0.1281	6.974×10^{-6}	5.20
HSA [35] with facts	0.12198	0.12243	0.1222	6.73×10^{-6}	9.58
IHSA [35] with facts	0.12065	0.12111	0.12091	6.81×10^{-6}	10.56
ALO (proposed)	0.1243	0.1257	0.1261	5.95×10^{-6}	7.85
WOA (proposed)	0.1228	0.1284	0.1279	5.79×10^{-6}	8.96
SCA (proposed)	***0.1193***	***0.11982***	***0.1196***	***4.73 x 10-6***	***11.56***

2.6. Test system 2: Standard IEEE-57 bus system

The standard IEEE 57-bus system consists of 80 transmission lines, seven generators at 1, 2, 3, 6, 8, 9, 12 and branches under load tap setting transformer branches. The reactive power sources are viewed as buses 18, 25 and 53. The system line data, bus information, variable limits and the initial values of the control variables were presented in [12,17,19,23,24]. The search space of this case system has 31 dimensions, including 7 generator voltages, 15 transformer taps and 3 reactive power sources with three SCR and TCSCs (location and sizing). The upper and lower boundaries of generation reactive

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power and control variable limits of trial system are given in Table 6. The entire system load is 1250.8 MW and 336.4 MVAr. The initial system active power loss is 28.462 MW.

Table 6:Limits of control variables for IEEE-57 bus system

Reactive power sources (pu)														
Q_C^{min}								Q_C^{max}						
Bus No	1	2	3	6	8	9	12	1	2	3	6	8	9	12
Values	−1.4	−0.17	−0.1	−0.08	−1.4	−0.03	−1.5	2.0	0.5	0.6	0.25	2.0	0.09	1.55
Generator voltages (pu)								***Transformer taps***						
V_G^{min}		V_G^{max}						T_i^{min}			T_i^{max}			
0.95		1.1						0.9			1.1			
SVC variables (pu)								***TCSC (pu)***						
Q_{svc}^{min}		Q_{svc}^{max}						X_{TCSC}^{min}		X_{TCSC}^{max}				
-0.3		*0.3*						-0.8X_{ij}		0.2X_{ij}				

Table 7:Best control variables settings and active power loss for IEEE 57 bus system

Control variables	***SCA (proposed)***	***WOA (proposed)***	***ALO (proposed)***	***HSA [36]***	***IHSA[36]***
V_1 (pu)	1.1000	1.1000	1.1000	1.0959	1.0951
V_2 (pu)	1.1000	1.1000	1.0986	1.0823	1.0876
V_3 (pu)	1.0768	1.1000	1.0865	1.0615	1.0730
V_6 (pu)	1.0558	1.1000	1.0789	1.0791	1.0768
V_8 (pu)	1.0566	1.1000	1.1000	1.0956	1.0978
V_9 (pu)	1.0795	1.1000	1.0865	1.0615	1.0687
V_{12},(pu)	1.1000	1.1000	1.0826	1.0543	1.0524
T_{4-18}	0.9037	0.9000	1.0983	1.0868	1.0914
T_{4-18}	1.0765	1.1000	1.0996	1.0431	1.0533
T_{21-20}	1.0284	1.1000	1.0822	1.0516	1.0374
T_{24-26}	0.9033	0.9000	1.0274	1.0448	1.0383
T_{7-29}	0.9998	0.9000	1.0593	1.0312	0.9993
T_{34-32}	0.9000	1.1000	1.0299	1.0654	1.0485
T_{11-41}	0.9637	0.9658	1.0757	0.972	0.96148
T_{15-45}	1.0515	0.9868	0.9911	0.97004	0.96166
T_{14-46}	1.0075	0.9075	1.0160	0.95267	0.94767
T_{10-51}	1.0257	0.9868	1.0395	0.98042	0.98225
T_{13-49}	1.0141	0.9000	0.9920	0.9645	0.93838
T_{11-43}	1.0432	0.9435	1.0431	1.0854	1.0779
T_{40-56}	0.9143	1.0554	0.9963	0.95482	0.9646
T_{39-57}	0.9753	1.0320	1.0450	1.0534	1.0720
T_{9-55}	0.9699	0.9410	1.0491	1.0224	1.0016
Q_{C-18} (MVAr)	11.3872	12.5971	13.0281	15.027	17.2000
Q_{C-25} (MVAr)	11.2767	10	24.602	2.2793	5.0562
Q_{C-53} (MVAr)	11.7701	20.3131	13.4127	15.376	16.1050
Q_{svc}(MVAr)	24.4867 (13)	24.7657 (2)	22.7575(45)	13.715(41)	25.5950 (37)
Q_{svc}(MVAr)	29.0054 (2)	11.8676(21)	23.6767(37)	10.717(33)	12.1650(13)
Q_{svc}(MVAr)	5.77056 (4)	4.76767(41)	10.77056 (13)	14.337 (45)	20.7940 (7)
X_{TCSC} *(pu)*	0.013891(2-3)	-0.12133(9-11)	0.12344(2-3)	0.26322 (54-55)	-0.0332(9-11)
X_{TCSC} *(pu)*	0.016119(8-9)	0.175543(36-40)	-0.12878(50-51)		
X_{TCSC} *(pu)*	0.01767(9-12)	0.176757(54-55)	0.044322(2-3)	0.13096 (50-51)	0.1166 (9-12)
P_{Loss} (MW)	**21.7272**	23.0555	23.7039	22.504	22.057

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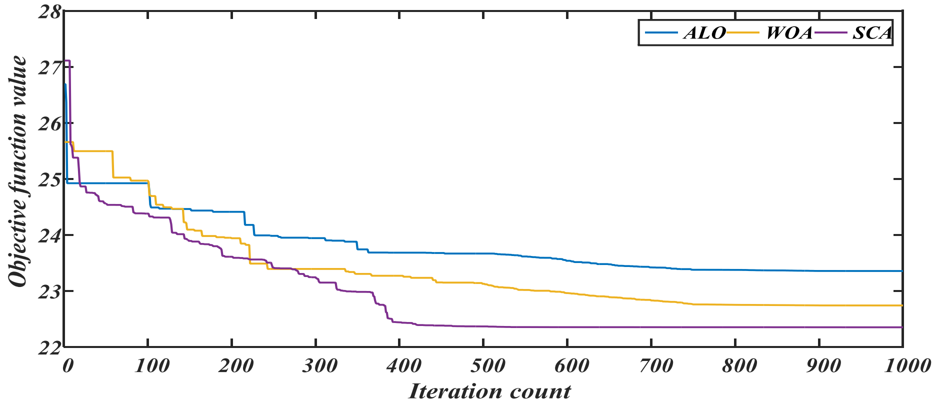

Figure11:Convergence characteristics of IEEE-57 bus system

Table 8: Best solutions of all algorithms for IEEE 57 bus system.

Algorithms	***Best (pu)***	***Worst (pu)***	***Mean (pu)***	***Std.Deviation***	***% P_{Save}***
NLP [16]	0.25902	0.30854	0.27858	1.167×10^{-2}	8.9934
CGA [16]	0.25244	0.27508	0.26294	6.295×10^{-3}	11.3059
AGA [16]	0.24565	0.26762	0.25128	6.006×10^{-3}	13.6925
PSO-w [16]	0.24271	0.26153	0.24726	7.014×10^{-3}	14.7266
PSO-cf[16]	0.24280	0.26033	0.24698	6.629×10^{-3}	14.6925
CLPSO [16]	0.24515	0.24781	0.24673	9.341×10^{-4}	13.8669
SPSO-07[16]	0.24430	0.25457	0.24752	2.833×10^{-3}	14.6925
L-DE [16]	0.27813	0.41909	0.33178	4.707×10^{-2}	13.8669
L-SACP-DE [16]	0.27916	0.36979	0.31033	3.223×10^{-2}	14.1647
L-SaDE[16]	0.24267	0.24391	0.24311	4.815×10^{-4}	14.2815
SOA [16]	0.24265	0.24280	0.24271	4.208×10^{-5}	14.7443
HSA [17]	0.24906	0.26965	0.25924	-	-
HSA [36]	0.23710	0.24272	0.23898	4.469×10^{-5}	16.6959
IHSA [36]	0.23448	0.24011	0.23755	4.177×10^{-5}	17.6165
HSA [36] with facts	0.22504	0.22534	0.22113	5.177 x 10-5	20.93
IHSA [36] with facts	0.22057	0.22098	0.22062	5.007 x 10-5	22.50
ALO (proposed)	0.23703	0.23855	0.23786	4.567×10^{-5}	16.66
WOA (proposed)	0.23055	0.23555	0.23455	4.877×10^{-5}	18.88
SCA (proposed)	***0.21727***	***0.21787***	***0.21755***	**4.054×10^{-5}**	***23.66***

Table 8 depicts the solution result for minimization of objective while the best reactive power dispatch solutions for this objective are tabulated. In Table 8, SCA based results are compared to other optimization technique recently reported in the literature like HSA [36] and IHSA [36]. Also, SCA results are compared with newest optimization techniques of ALO and WOA.

In [19], base case power loss for this test power network is reported as 28.462 MW. The percentage save of power loss demonstrates that a power loss reduction of 23.66% (from 28.462 MW to 21.727 MW) is accomplished by using the proposed SCA approach, which is the highest reduction of power loss than that obtained by the other approaches in the literature. Comparative ALO, WOA and SCA based convergence profiles of objective function for this test power system is presented in Fig. 11. From this figure it may be observed that the convergence profile for the proposed SCA based approach for this test system is capable one.

2.7. Test system 3: Standard IEEE-118 bus system

To test the proposed technique in solving larger power systems, a standard IEEE 118-bus test system is considered. The search space of this case system has 83 dimensions, that is, the 54 generator buses, 64 load buses, 186 transmission lines, 9 transformer taps and 14 reactive power sources addition with 3 SCRs and 3 TCSCs. The system line data, bus data, variable limits and the initial values of control variables were given in [19,23,25, 29]. The maximum and minimum limits of reactive power sources, voltage and tap-setting limits are given in Tables 9 respectively. The system loads are given as follows P_{load} = 4242 MW, Q_{load} = 1438 MVAr.The total power losses are as P_{loss}=132.283 MW.

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Table 9:Limits of control variables for IEEE-118 bus system

Reactive power sources **(MVAr)**														
	Q_C^{min}							Q_C^{max}						
Bus No	5	34	37	44	45	46	48	5	34	37	44	45	46	48
Values	-40	0	-25	0	0	0	0	0	14	0	10	10	10	15
Bus No	74	79	82	83	105	107	110	74	79	82	83	105	107	110
Values	0	0	0	0	0	0	0	12	20	20	10	20	6	6
Generator voltages **(pu)**								***Transformer tap***						
V_G^{min}			V_G^{max}					T_i^{min}		T_i^{max}				
0.95			1.1					0.9		1.1				
SVC variables (pu)								***TCSC (pu)***						
Q_{svc}^{min}			Q_{svc}^{max}					Q_{svc}^{min}		Q_{svc}^{max}				
-0.3			*0.3*					*-0.3*		*0.3*				

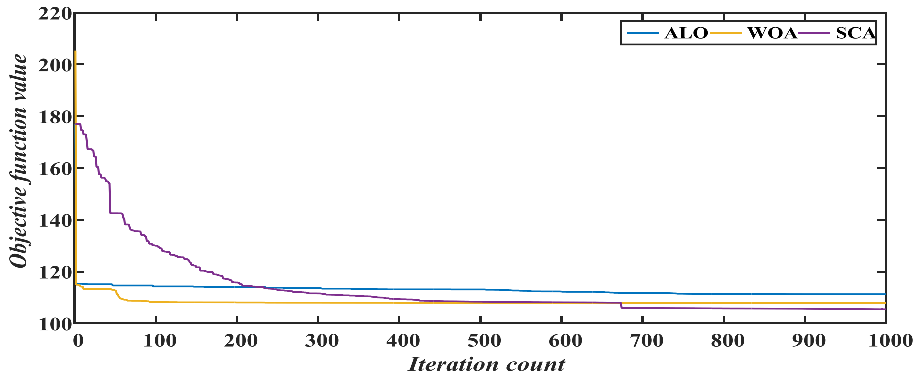

Figure 12:Convergence characteristics of IEEE-118 bus system

Table 10:Best control variables settings and active power loss for IEEE-118 bus system

	With FACTS devices			***Conventional ORPD alone***					
Control variables	***SCA (proposed)***	***WOA (proposed)***	***ALO (proposed)***	***ICA [23]***	***IWO [23]***	***MICA-IWO [23]***	***GSA [19]***	***PSO[19]***	***CLPSO[19]***
V_1(pu)	1.082472	1.087637	1.048895	1.0080	0.9978	1.0419	0.9600	1.0853	1.0332
V_4 (pu)	1.083338	1.087637	1.049046	1.0296	1.0378	1.0600	0.9620	1.0420	1.0550
V_6 (pu)	1.080483	1.085874	1.048895	1.0149	1.0189	1.0542	0.9729	1.0805	0.9754
V_8 (pu)	1.07779	1.087637	1.04902	1.0381	0.9922	1.0582	1.0570	0.9683	0.9669
V_{10} (pu)	1.076733	1.086423	1.049895	1.0600	1.0245	1.0600	1.0885	1.0756	0.9811
V_{12} (pu)	1.078168	1.087637	1.049544	1.0131	1.0087	1.0511	0.9630	1.0225	1.0092
V_{15} (pu)	1.081264	1.087637	1.049418	1.0006	0.9804	1.0498	1.0127	1.0786	0.9787
V_{18} (pu)	1.081803	1.085983	1.049552	0.9987	0.9883	1.0525	1.0069	1.0498	1.0799
V_{19} (pu)	1.082496	1.087637	1.049648	1.0036	0.9862	1.0490	1.0003	1.0776	1.0805
V_{24} (pu)	1.077607	1.087637	1.048988	1.0388	0.9673	1.0528	1.0105	1.0827	1.0286
V_{25} (pu)	1.073081	1.087637	1.048895	1.0600	1.0515	1.0600	1.0102	0.9564	1.0307
V_{26} (pu)	1.083363	1.087637	1.049297	1.0600	0.9948	1.0600	1.0401	1.0809	0.9877
V_{27} (pu)	1.081682	1.087637	1.048895	1.0093	0.9829	1.0466	0.9809	1.0874	1.0157
V_{31} (pu)	1.08228	1.087637	1.048895	0.9958	0.9461	1.0430	0.9500	0.9608	0.9615
V_{32} (pu)	1.08213	1.085809	1.049384	1.0016	0.9532	1.0453	0.9552	1.1000	0.9851
V_{34} (pu)	1.083463	1.087637	1.049691	1.0267	1.0099	1.0600	0.9910	0.9611	1.0157
V_{36} (pu)	1.0837	1.087637	1.04975	1.0257	1.0019	1.0584	1.0091	1.0367	1.0849
V_{40} (pu)	1.080107	1.087637	1.048895	1.0181	0.9886	1.0384	0.9505	1.0914	0.9830
V_{42} (pu)	1.081575	1.087637	1.049483	1.0285	0.9559	1.0398	0.9500	0.9701	1.0516
V_{46} (pu)	1.084271	1.087637	1.048895	1.0409	1.0205	1.0470	0.9814	1.0390	0.9754
V_{49} (pu)	1.080453	1.087637	1.048898	1.0535	1.0528	1.0600	1.0444	1.0836	0.9838
V_{54} (pu)	1.080622	1.086017	1.048895	1.0291	1.0146	1.0388	1.0379	0.9764	0.9637

V_{55} (pu)	1.082479	1.087637	1.049464	1.0285	1.0149	1.0380	0.9907	1.0103	0.9716
V_{56} (pu)	1.081206	1.087637	1.048895	1.0286	1.0162	1.0382	1.0333	0.9536	1.0250
V_{59} (pu)	1.081425	1.087637	1.049021	1.0478	1.0046	1.0600	1.0099	0.9672	1.0003
V_{61} (pu)	1.082719	1.086914	1.049619	1.0406	1.0468	1.0600	1.0925	1.0938	1.0771
V_{62} (pu)	1.083514	1.085743	1.049477	1.0346	1.0547	1.0559	1.0393	1.0978	1.0480
V_{65} (pu)	1.082064	1.085362	1.048895	1.0600	1.0547	1.0600	0.9998	1.0892	0.9684
V_{66} (pu)	1.083611	1.087637	1.049013	1.0600	1.0572	1.0600	1.0355	1.0861	0.9648
V_{69} (pu)	1.081332	1.087637	1.048895	1.0600	1.0599	1.0600	1.1000	0.9665	0.9574
V_{70} (pu)	1.085016	1.087637	1.048895	1.0371	1.0297	1.0377	1.0992	1.0783	0.9765
V_{72} (pu)	1.080457	1.087637	1.048895	1.0390	0.9832	1.0430	1.0014	0.9506	1.0243
V_{73} (pu)	1.08344	1.087637	1.048895	1.0411	1.0030	1.0374	1.0111	0.9722	0.9651
V_{74} (pu)	1.077322	1.087637	1.049577	1.0235	1.0239	1.0275	1.0476	0.9713	1.0733
V_{76} (pu)	1.083105	1.087637	1.048895	1.0107	0.9474	1.0253	1.0211	0.9602	1.0302
V_{77} (pu)	1.082106	1.087637	1.048895	1.0297	1.0311	1.0473	1.0187	1.0781	1.0275
V_{80} (pu)	1.081767	1.087637	1.048895	1.0389	1.0510	1.0600	1.0462	1.0788	0.9857
V_{85} (pu)	1.080431	1.087637	1.049744	1.0514	1.0070	1.0600	1.0491	0.9568	0.9836
V_{87} (pu)	1.082422	1.087637	1.048895	1.0417	0.9421	1.0600	1.0426	0.9642	1.0882
V_{89} (pu)	1.083053	1.087637	1.048963	1.0600	1.0562	1.0600	1.0955	0.9748	0.9895
V_{90} (pu)	1.082293	1.087637	1.04913	1.0340	1.0389	1.0445	1.0417	1.0248	0.9905
V_{91} (pu)	1.081724	1.08608	1.048895	1.0374	1.0198	1.0496	1.0032	0.9615	1.0288
V_{92} (pu)	1.081534	1.087637	1.048895	1.0470	1.0167	1.0600	1.0927	0.9568	0.9760
V_{99} (pu)	1.082929	1.087637	1.048895	1.0309	1.0588	1.0560	1.0433	0.9540	1.0880
V_{100} (pu)	1.083526	1.087637	1.049271	1.0257	1.0332	1.0600	1.0786	0.9584	0.9617
V_{103} (pu)	1.079498	1.087637	1.049037	1.0113	1.0141	1.0600	1.0266	1.0162	0.9611
V_{104} (pu)	1.082023	1.087637	1.04937	0.9949	1.0063	1.0518	0.9808	1.0992	1.0125
V_{105} (pu)	1.083416	1.087637	1.048941	0.9923	0.9945	1.0517	1.0163	0.9694	1.0684
V_{107} (pu)	1.079004	1.087637	1.049361	0.9800	0.9487	1.0389	0.9987	0.9656	0.9769
V_{110} (pu)	1.083079	1.087637	1.048952	0.9984	1.0441	1.0508	1.0218	1.0873	1.0414
V_{111} (pu)	1.08312	1.086442	1.048895	1.0080	0.9743	1.0600	0.9852	1.0375	0.9790
V_{112} (pu)	1.080024	1.08502	1.049312	0.9823	0.9863	1.0358	0.9500	1.0920	0.9764
V_{113} (pu)	1.079411	1.087637	1.049192	0.9786	0.9771	1.0600	0.9764	1.0753	0.9721
V_{116} (pu)	1.082748	1.087637	1.048895	1.0473	1.0566	1.0600	1.0372	0.9594	1.0330
T_{5-8}	0.998432	0.989228	0.990939	0.9900	1.0400	1.0000	1.0659	1.0112	1.0045
T_{25-26}	1.001418	0.989132	0.990341	1.1000	0.9900	1.1000	0.9534	1.0906	1.0609
T_{17-30}	0.996509	0.988683	0.990985	1.0300	1.0800	0.9900	0.9328	1.0033	1.0008
T_{37-38}	0.994913	0.989294	0.990341	1.0100	1.0400	0.9800	1.0884	1.0000	1.0093
T_{59-63}	0.996932	0.988844	0.991035	0.9800	0.9500	0.9800	1.0579	1.0080	0.9922
T_{61-64}	0.975139	0.988621	0.990341	1.0100	1.0200	1.0000	0.9493	1.0326	1.0074
T_{65-66}	0.985599	0.988683	0.984905	0.9400	0.9500	0.9000	0.9975	0.9443	1.0611
T_{68-69}	1.00101	0.989421	0.995988	0.9800	0.9300	0.9500	0.9887	0.9067	0.9307
T_{80-81}	0.998315	0.988447	0.993019	0.9900	1.0300	0.9900	0.9801	0.9673	0.9578
Q_{c5} (MVAr)	-7.0704	-0.00581	-34.8753	-0.0732	-0.2064	-0.4	0.0000	0.0000	0.0000
Q_{C34} (MVAr)	7.765352	11.69995	8.450712	0.0477	0.1382	0.1400	7.4600	9.3639	11.7135
Q_{C37} (MVAr)	-9.21773	-5.25315	-9.56137	-0.1268	-0.0117	0.0000	0.0000	0.0000	0.0000
Q_{c44} (MVAr)	3.150744	5.510977	0.999554	0.0000	0.0081	0.0429	6.0700	9.3078	9.8932
Q_{C45} (MVAr)	7.528823	7.636399	8.649973	0.0505	0.0053	0.0073	3.3300	8.6428	9.4169
Q_{c46} (MVAr)	0	2.804123	9.31467	0.0669	0.0199	0.0697	6.5100	8.9462	2.6719
Q_{c48} (MVAr)	1.644068	9.910066	14.99576	0.0321	0.1461	0.0368	4.4700	11.8092	2.8546
Q_{c74} (MVAr)	10.55347	0	10.40067	0.0000	0.0081	0.0000	9.7200	4.6132	0.5471
Q_{c79} (MVAr)	3.158644	7.858706	19.99434	0.0000	0.1537	0.0000	14.2500	10.5923	14.8532
Q_{c82} (MVAr)	14.51898	0	12.93793	0.0000	0.0037	0.0000	17.4900	16.4544	19.4270
Q_{C83} (MVAr)	7.555023	1.153496	1.30626	0.0260	0.0367	0.0000	4.2800	9.6325	6.9824
Q_{c105} (MVAr)	0	0	17.39852	0.1995	0.0265	0.0001	12.0400	8.9513	9.0291

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Q_{c107} (MVAr)	4.550553	0	1.371621	0.0235	0.0587	0.0016	2.2600	5.0426	4.9926
Q_{c110} (MVAr)	4.367863	3.516079	1.336279	0.0483	0.0486	0.0002	2.9400	5.5319	2.2086
Q_{svc}(MVAr)	10.762(20)	21.654(90)	11.786(96)						
Q_{svc}(MVAr)	21.087(68)	10.767(75)	8.654(34)						
Q_{svc}(MVAr)	17.868(106)	21.867(15)	21.767(109)						
X_{TCSC} *(pu)*	0.0172(12-16	0.1278(96-97)	0.2171(51-52)	***NA***	***NA***	***NA***	***NA***	***NA***	***NA***
X_{TCSC} *(pu)*	0.1129(65-68)	0.0289(106-107)	0.5442(70-71)						
X_{TCSC} *(pu)*	0.6533(94-93)	0.4876(28-29)	0.3215(13-15)						
P_{Loss} *(MW)*	**103.54**	106.62	110.645	118.32	137.30	114.05	127.760	131.990	130.960

Table 11: Best solutions of all algorithms for IEEE 118 bus system

Algorithms	***Best (pu)***	***Worst (pu)***	***Mean (pu)***	***Std. Dev***	***% Psave***
ICA [23]	1.18322	1.21527	1.18970	6.4261×10^{-3}	11.27
IWO [23]	1.37295	1.56288	1.45752	9.4227×10^{-2}	-2.95
MICA-IWO [23]	1.14046	1.14976	1.14448	2.4288×10^{-4}	14.48
RGA [23]	1.22140	1.26696	1.24089	1.791×10^{-2}	-
CMAES [23]	1.19275	1.21860	1.20854	8.62×10^{-3}	-
MOPSO [23]	1.19581	-	-	-	-
NSGA-II [23]	1.19580	-	-	-	-
MNSGA-II [23]	1.19279	-	-	-	-
DMSDE [23]	1.15370	-	1.16840	8.787×10^{-3}	13.4879
PSO-cf [23]	1.15821	-	1.18827	1.7248×10^{-2}	13.1496
PSO-w [23]	1.15833	-	1.20575	2.3574×10^{-2}	13.1408
AGA [23]	1.23964	-	1.27827	2.0613×10^{-2}	17.0438
MVMO [23]	1.15793	1.19358	1.16820	7.682×10^{-3}	-
PSO [23]	1.20897	1.35372	1.25487	3.1634×10^{-2}	-
DE [23]	1.25025	1.30229	1.27442	1.1337×10^{-2}	-
JADE [23]	1.19161	1.32035	1.22677	3.0467×10^{-2}	-
JADE-vPS [23]	1.19201	1.33344	1.25575	3.8943×10^{-2}	-
CGA [23]	1.39415	1.49009	1.43548	2.6026×10^{-2}	-
AGA [23]	1.24209	1.31078	1.27701	1.836×10^{-2}	-
PSO-w [23]	1.15815	1.18214	1.16771	6.8971×10^{-3}	-
PSO-cf [23]	1.15642	1.18058	1.16202	6.1864×10^{-3}	-
CLPSO [23]	1.23152	1.25499	1.24080	6.4325×10^{-3}	-
SPSO-07 [23]	1.39275	1.50244	1.46266	2.653×10^{-2}	-
L-DE [23]	1.51009	1.76614	1.62315	8.2443×10^{-2}	-
L-SACP-DE [23]	1.41799	1.76812	1.60679	1.0643×10^{-1}	-
L-SaDE [23]	1.16906	1.18862	1.17598	5.4041×10^{-3}	-
SOA [12]	1.14950	1.16347	1.15674	3.5908×10^{-3}	-
ALO (proposed)	1.1064	1.12065	1.11233	3.2083×10^{-3}	16.36
WOA (proposed)	1.0662	1.08467	1.07865	3.1434×10^{-3}	19.40
SCA (proposed)	1.0354	**1.05321**	**1.04566**	$\mathbf{2.3256 \times 10^{-3}}$	**21.72**

SCA based reactive power dispatch schedule for the trial system of power loss minimization objective is presented in Table 10 and the results obtained are compared to ICA [23]; IWO [23]; MICA-IWO [23]; GSA [19]; PSO [19]; CLPSO [19], ALO and WOA. This table proves that the SCA yield optimal loss as compared to other algorithms. Table 11 records the statistical comparison of effects obtained from SCA with existing results presented in the literature. From this table, noted that the standard deviation and median values are quite acceptable for SCA. Good convergence profile of the SCA may be noticed from this Fig. 12 by way of its ability to achieve the approximate optimal solution.

3. Conclusion

In the proposed work, three newest optimization techniques (SCA, WOA and ALO) are applied for effective co-ordination of series and shunt FACTS devices with the control variables present in a connected power system. To obtain reactive power optimization with FACTS devices, the execution of three algorithms has been carried out on the IEEE 14-bus, 57-bus, and large118-bus schemes. SCA was one among various optimization methods that creates better outcomes compared with existing literatures. Maintenance of voltage profile, reduction of power loss, and optimization of reactive power have been facilitated by the algorithm. Hence SCA may be seen as a very good optimization technique in the field of power system planning and future research credentials.

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