OPTIMAL REACTIVE POWER DISPATCH WITH SERIES AND SHUNT FACTS DEVICES USING SINE COSINE ALGORITHM

R. Ravisekar

Research Scholar, Electrical and Electronics Engineering Dept.
Bharath Institute of Higher Education and Research Chennai, India

Dr. K. Srinivasan

Professor and Head Electrical and Electronics Engineering Dept.
Tagore Engineering. College, Chennai, India

ABSTRACT

Management of reactive power resources is essential for the secure and stable functioning of power systems in the standpoint of voltage stability. The principal aim 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 meeting a given lot of constraints. In this paper, Flexible AC Transmission System (FACTS) controllers named as Unified Power Flow Controller (UPFC) is added with conventional ORPD problem for active power loss minimization with voltage profile improvement. Also, this paper demonstrates the application of sine cosine algorithm (SCA) to discover the optimal solution of ORPD (with UPFC) of power system with different test systems (IEEE 57-bus and IEEE 118-bus) with distinct cases such as minimization of active power losses and improvement of voltage profile. Simulation results show the high quality 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 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

Cite this Article: R. Ravisekar and Dr. K. Srinivasan, Optimal Reactive Power Dispatch with Series and Shunt Facts Devices using Sine Cosine Algorithm, *International Journal of Advanced Research in Engineering and Technology (IJARET)*, 11 (1), 2020, pp 90-109.

<http://iaeme.com/Home/issue/IJARET?Volume=11&Issue=1>

1. INTRODUCTION

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

According 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 optimise the objective function by linearising it. Since the ORPD problem has local optima more than one, it is a non-linear and multi-modal optimisation problem. Hence, it is so hard to find the global optimum using mathematical algorithms in solution of the ORPD problem. Nevertheless, there are some disadvantages special to the algorithms such as insecure convergence and algorithmic complexity. For these reasons, researchers were developed heuristic and meta heuristic based algorithms for solving the ORPD problem was presented 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.	HFA	Power loss and voltage	IEEE 30-bus and IEEE 118-bus

Malakar (2015) [25]		deviation	
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) is a new meta-heuristic search algorithm. It has been proposed by Seyedali Mirjalili in 2016. It has been reported in [34] that the SCA has a lot of advantages and it is different from the other meta heuristic algorithms like GSA etc. These are expressed in detail in [34]. Moreover, in [34], SCA has been examined on 19 different standard benchmark functions and aircraft design problem compared with other meta heuristic algorithms such as Firefly Algorithm (FA), Bat Algorithm (BA), Flower Pollination Algorithm (FPA) and Gravitational Search Algorithm (GSA).

It was found that the results obtained by SCA in most cases provide superior results and in all cases are comparable with others. The most substantial feature of the SCA is that creating multiple initial random candidate solutions and requires them to fluctuate outwards or towards the best solution using 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.

Continuous and fast improvement of power electronics technology has made FACTS as a promising concept for power system applications during the last decade [35,36]. The use of FACTS controllers provides a flexible controlling of power flow along the transmission lines. It can reduce the flows of heavily loaded lines, maintain the bus voltages at desired levels, and improve the stability of the power network. The UPFC [36-38] is the most versatile FACTS controller envisaged so far. It can not only perform the functions of the STATCOM, TCSC and the phase angle regulator but also provides additional flexibility by combining some of the functions of the above controllers. The UPFC can provide simultaneous control of all basic power system parameters. It can fulfill functions of reactive shunt compensation, series compensation and phase shifting meeting multiple control objectives. From a functional perspective, the objectives are met by applying a boosting transformer injected voltage and an exciting transformer reactive current. The injected voltage is inserted by a series transformer.

In order to evaluate the proposed algorithm with UPFC, it was tested on IEEE 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.

2. 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 provide reactive power compensation and series compensator is used to enhance the power flow.

Gyugyi in 1991 proposed the Unified Power Flow Controller. It is the most versatile and complex power electronic device and member of third generation FACTS Controller introduced to control the power flow and voltage in the power systems. It is designed by combining the features of second-generation FACTS controllers – Series Synchronous Compensator (SSSC) and Static Synchronous Compensator (STATCOM). It has the ability to control active and reactive power flow of a transmission line simultaneously in addition to controlling all the transmission parameters (voltage, impedance and phase angle) affecting the power flow in a transmission line [35-38].

2.1. Modeling of UPFC

Figure.1 UPFC model

The above figure 1 taken from reference [36] gives a clear description about how UPFC controller connected to a transmission line. It consists of two back-to-back self-commutated voltage source converters - one converter at the sending end is connected in shunt as shunt converter and the other converter connected in between sending and receiving end bus in series as series converter. One end of the both the converters are connected to a power system through an appropriate transformer and other end connected with a common DC capacitor link [36].

2.2. Operation of UPFC

This arrangement of UPFC ideally works as an ideal ac to dc power converter in which real power can freely flow in either direction between ac terminals of the two converters and each converter can independently generate or absorb reactive power at its own AC output terminal. The main functionality of UPFC provided by shunt converter by injecting an ac voltage considered as a synchronous ac voltage source with controllable phase angle and magnitude in series with the line. The transmission line current flowing through this voltage source results in real and reactive power exchange between it and the AC transmission system. The inverter converts the real power exchanged at ac terminals into dc power which appears at the dc link as positive or negative real power demand [37].

Optimal Reactive Power Dispatch with Series and Shunt Facts Devices using Sine Cosine Algorithm

- Power flow as a series reactive compensation controlled by injecting a series voltage V_{se}' in quadrature to the line current.
- Power flow as phase shifter controlled by injecting a series voltage of magnitude V_{se}'' in quadrature to node voltage θ_m [38].

2.4.1. UPFC power Equations

Based on the equivalent circuit as shown in Fig 4.2, the active and reactive power equations can be written as follows [27, 7]:

At node k:

$$P_k = V_k^2 G_{kk} + V_k V_m (G_{km} \cos(\theta_k - \theta_m) + B_{km} \sin(\theta_k - \theta_m)) + V_k V_{se} (G_{km} \cos(\theta_k - \theta_{se}) + B_{km} \sin(\theta_k - \theta_{se})) + V_k V_{sh} (G_{sh} \cos(\theta_k - \theta_{sh}) + B_{sh} \sin(\theta_k - \theta_{sh})) \quad (3)$$

$$Q_k = -V_k^2 B_{kk} + V_k V_m (G_{km} \sin(\theta_k - \theta_m) - B_{km} \cos(\theta_k - \theta_m)) + V_k V_{se} (G_{km} \sin(\theta_k - \theta_{se}) - B_{km} \cos(\theta_k - \theta_{se})) + V_k V_{sh} (G_{sh} \sin(\theta_k - \theta_{sh}) - B_{sh} \cos(\theta_k - \theta_{sh})) \quad (4)$$

At node m:

$$P_m = V_m^2 G_{mm} + V_m V_k (G_{mk} \cos(\theta_m - \theta_k) + B_{mk} \sin(\theta_m - \theta_k)) + V_m V_{se} (G_{mm} \cos(\theta_m - \theta_{se}) + B_{mm} \sin(\theta_m - \theta_{se})) \quad (5)$$

$$Q_m = -V_m^2 B_{mm} + V_m V_k (G_{mk} \sin(\theta_m - \theta_k) - B_{mk} \cos(\theta_m - \theta_k)) + V_m V_{sh} (G_{mm} \sin(\theta_m - \theta_{se}) - B_{mm} \cos(\theta_m - \theta_{se})) \quad (6)$$

Series converter:

$$P_{se} = V_{se}^2 G_{mm} + V_{se} V_k (G_{km} \cos(\theta_{se} - \theta_k) + B_{km} \sin(\theta_{se} - \theta_k)) + V_{se} V_m (G_{mm} \cos(\theta_{se} - \theta_m) + B_{mm} \sin(\theta_{se} - \theta_m)) \quad (7)$$

$$Q_{se} = -V_{se}^2 B_{mm} + V_{se} V_k (G_{km} \sin(\theta_{se} - \theta_k) - B_{km} \cos(\theta_{se} - \theta_k)) + V_{se} V_m (G_{mm} \sin(\theta_{se} - \theta_m) - B_{mm} \cos(\theta_{se} - \theta_m))$$

Shunt converter:

$$P_{sh} = -V_{sh}^2 G_{sh} + V_{sh} V_k (G_{sh} \cos(\theta_{sh} - \theta_k) + B_{sh} \sin(\theta_{sh} - \theta_k)) \quad (8)$$

$$Q_{sh} = V_{sh}^2 B_{sh} + V_{sh} V_k (G_{sh} \sin(\theta_{sh} - \theta_k) - B_{sh} \cos(\theta_{sh} - \theta_k)) \quad (9)$$

Where

$$Y_{kk} = G_{kk} + jB_{kk} = Z_{se}^{-1} + Z_{sh}^{-1} \quad (10)$$

$$Y_{mm} = G_{mm} + jB_{mm} = Z_{se}^{-1} \quad (11)$$

$$Y_{km} = Y_{mk} = G_{km} + jB_{km} = -Z_{se}^{-1} \quad (12)$$

$$Y_{sh} = G_{sh} + jB_{sh} = -Z_{sh}^{-1} \quad (13)$$

Assuming a free converter loss operation, the active power supplied to the shunt converter P_{sh} equals to the active power demanded by the series converter P_{se} [36].

$$P_{se} + P_{sh} = 0 \quad (14)$$

Furthermore, if the coupling transformers are assumed to contain no resistance then the active power at bus k matches the active power at bus m; that is,

$$P_{sh} + P_{se} = P_k + P_m = 0 \quad (15)$$

The UPFC power equations linearised and combined with the equations of the AC transmission network. For the cases when the UPFC controls the following parameters:

- voltage magnitude at the shunt converter terminal
- active power flow from bus m to bus k and
- reactive power injected at bus m, and taking bus m to be PQ bus.

3. 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.

3.1. Minimization of real power losses

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

$$F_1 = \sum_{k=1}^{NT} P_{loss,k} = \sum_{k=1}^{NT} G_k (V_i^2 + V_j^2) - 2V_i V_j \cos(\delta_i - \delta_j) \quad (16)$$

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.

3.2. Improvement of Voltage Profile

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

$$F_2 = \sum_{i=1}^{NPQ} |V_{i,spec} - V_i| \quad (17)$$

where NPQ is the number of load buses in the power system and V_i is the reference value of the voltage magnitude of the i^{th} bus which is equal to 1.0 (pu)

By combining the Eq.(16) and Eq. (17) leads to the main objective function as follows:

$$F_{obj} = F_1 + F_2 = \left(\sum_{k=1}^{NT} P_{loss,k} \right) + \left(\sum_{i=1}^{NPQ} |V_{i,spec} - V_i| \right) \quad (18)$$

3.3. Constraints

3.3.1. Equality Constraints

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

$$P_{Gi} - P_{Di} - \sum_{j \in NB} V_i V_j (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) = 0 \quad (19)$$

$$Q_{Gi} - Q_{Di} - \sum_{j \in NB} V_i V_j (G_{ij} \sin \delta_{ij} + B_{ij} \cos \delta_{ij}) = 0 \quad (20)$$

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.

3.3.2. Inequality Constraints

Generator Constraints

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

$$Q_{G,i}^{\min} \leq Q_{G,i} \leq Q_{G,i}^{\max} \quad i \in NG \quad (21)$$

$$V_{G,i}^{\min} \leq V_{G,i} \leq V_{G,i}^{\max} \quad i \in NG \quad (22)$$

Transformer Constraints

Transformer tap setting are bounded as follows:

$$T_i^{\min} \leq T_i \leq T_i^{\max} \quad i \in \text{No of transformers} \quad (23)$$

Shunt VAR Compensator Constraints

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

$$Q_{C,i}^{\min} \leq Q_{C,i} \leq Q_{C,i}^{\max} \quad i \in NC \quad (24)$$

Security Constraints

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

$$V_{L,i}^{\min} \leq V_{L,i} \leq V_{L,i}^{\max} \quad i \in NPQ \quad (25)$$

$$S_{L,i} \leq S_{L,i}^{\max} \quad i \in NT \quad (26)$$

Eq. (18) and Eq. (19) are changed to the following form using penalty terms to the objective function:

$$F_{new} = F_{obj} + \lambda_V \sum_{i=1}^{NPQ} (V_i - V_i^{\lim})^2 + \lambda_Q \sum_{i=1}^{NG} (Q_{G,i} - Q_{G,i}^{\lim})^2 \quad (27)$$

$x^{\lim}$ is the limit value of the dependent variable $x = (V_i \text{ and } Q_G)$ and given as:

$$x^{\lim} = x^{\max} \text{ if } x > x^{\max}, \text{ and } x^{\lim} = x^{\min} \text{ if } x < x^{\min}$$

Where λ_V and λ_Q are the weighting factors to enhance the objective function.

4. SINE COSINE OPTIMIZATION ALGORITHM

Irrespective of the differences between algorithms in the area of stochastic population-based optimization, the green is the variance of the optimization process to two phases: exploration versus exploitation. In the late phase, an optimization algorithm combines the random

solutions in the set of solutions abruptly with a high rate of randomness to find the bright regions of the search space. In the exploitation phase, however, there are gradual changes in the random solutions, and random variations are considerably less than those in the exploration phase.

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

$$X_i^{t+1} = X_i^t + r_1 \times \sin(r_2) \times \|r_3 P_i^t - X_i^t\| \quad (28)$$

$$X_i^{t+1} = X_i^t + r_1 \times \cos(r_2) \times \|r_3 P_i^t - X_i^t\| \quad (29)$$

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. (28) and Eq. (29), it will be used as,

$$X_i^{t+1} = \begin{cases} X_i^t + r_1 \times \sin(r_2) \times \|r_3 P_i^t - X_i^t\| & r_4 < 0.5 \\ X_i^t + r_1 \times \cos(r_2) \times \|r_3 P_i^t - X_i^t\| & r_4 \geq 0.5 \end{cases} \quad (30)$$

where r_4 is a random number in $[0,1]$.

From the Eq. (28), 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 r_4 equally switches between the sin and cosine components in Eq. (27).

Figure. 3. Properties of Sine and Cosine on the next position

The effects of Sine and Cosine on Eqs. (28) and (29) are illustrated in Fig. 3. This figure shows that how the proposed equations define, a space between two solutions in the search

space. It should be mentioned that this equality can be stretched to higher dimensions, although a two-dimensional example is exemplified in Fig. 3. The cyclic form 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 answers. For researching the search space, the solutions should be able to seek outside the space between their corresponding destinations as well. This can be accomplished by shifting the orbit of the sine 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 bottom or outside is achieved by specifying a random number for r_2 in $[0, 2\pi]$ in Eq. (30). Thus, this mechanism guarantees exploration and exploitation of the search space respectively.

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

The following equation is used to update the value of r_1 in Eqs. (27) to (30),

$$r_1 = a - t \frac{a}{T} \quad (31)$$

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.

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

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

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

$$X^T = [V_{G1} \dots V_{GNPV}, Q_{C1} \dots Q_{CNC}, T_1 \dots T_{NT}]$$

Step 2: Perform Newton Raphson load flow analysis, and ascertain the solution using Eq. (27) 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 its satisfied, *publish the best solution (objective function and control variables)* else *Update the position of search agents using Eq. (30) and goto step 2.*

5. TEST SYSTEMS

In this paper, sine cosine algorithm is applied to standard 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 and Fig. 8 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].

Figure 7. Single line diagram of IEEE-57 bus system

Figure 8. Single line diagram of IEEE-118 bus system

Table 2. Description of test systems – Base case

Description	IEEE 57-bus	IEEE 118-bus
Buses	57	118
Generators	7	54
Transformers	15	9
Shunts	3	14
Branches	80	186
Control variables	25	77
Base case P_{Load} (MW)	1250.80	4242
Base case Q_{Load} (MVar)	336.40	1438

6. RESULTS AND DISCUSSION

6.1. Test System 1: 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 22 dimensions, including 7 generator voltages, 15 transformer taps. The upper and lower boundaries of generation reactive power and control variable limits of trial system are given in Table 3. The lower and upper limits of the series voltage sources of the UPFC are taken within the interval of 0–0.2 p.u., respectively, and the limiting values of the shunt voltage sources of the UPFC are taken in between 0 and 1.1 p.u. The phase angles of these sources are within the range of 0– 2π . The shunt and series impedances of installed UPFC are taken as $(0.01 + j0.1)$ p.u. and $(0.001 + j0.2)$ p.u., respectively. The entire system load is 1250.8 MW and 336.4 MVar. In order to analyze the

Optimal Reactive Power Dispatch with Series and Shunt Facts Devices using Sine Cosine Algorithm

system under stressed condition, active and reactive power demand of each load bus are multiplied by 1.25 [41].

Table 3. 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_l^{min}			T_l^{max}			
0.95			1.1					0.9			1.1			

Table 4. Best control variables settings and active power loss for IEEE 57 bus system (with UPFC)

Control variables	SCA (proposed)	BBO [41]	DE[41]	KHA[41]	OKHA[41]
V_1 (pu)	1.1000	1.0537	1.0440	1.0537	1.0467
V_2 (pu)	1.1000	1.0512	1.0316	1.0449	1.0441
V_3 (pu)	1.0768	1.0199	1.0210	1.0211	1.0196
V_6 (pu)	1.0558	0.9978	0.9983	1.0022	1.0152
V_8 (pu)	1.0566	1.0408	1.0358	1.0336	1.0288
V_9 (pu)	1.0795	1.0299	1.0359	1.0335	1.0296
V_{12} (pu)	1.1000	1.0003	1.0023	1.0003	1.0080
T_{4-18}	0.9937	1.0036	0.9462	1.0199	0.9181
T_{4-18}	1.0765	0.9436	1.0174	0.9591	1.0687
T_{21-20}	1.0284	0.9866	0.9781	0.9731	0.9879
T_{24-26}	0.9033	1.0836	1.0982	1.0817	1.0937
T_{7-29}	0.9998	0.9361	0.9281	0.9361	0.9248
T_{34-32}	0.9100	0.9007	0.9006	0.9002	0.9016
T_{11-41}	0.9637	0.9062	0.9014	0.9062	0.9172
T_{15-45}	1.0515	0.9108	0.9025	0.9108	0.9273
T_{14-46}	1.0075	0.9473	0.9498	0.9543	0.9271
T_{10-51}	1.0257	0.9832	1.0018	0.9828	0.9904
T_{13-49}	1.0141	0.9017	0.9079	0.9017	0.9012
T_{11-43}	1.0432	0.9066	0.9195	0.9042	0.9267
T_{40-56}	0.9943	1.0617	1.0379	1.0605	1.0161
T_{39-57}	0.9753	0.9036	0.9222	0.9188	0.9593
T_{9-55}	0.9999	0.9968	1.0100	0.9946	1.0223
Q_{C-18} (pu)	0.0654	0.0246	0.0618	0.0236	0.0631
Q_{C-25} (pu)	0.0432	0.0581	0.0585	0.0583	0.0566
Q_{C-53} (pu)	0.4505	0.0602	0.0581	0.0619	0.0465

Table 5. Best solutions of all algorithms for IEEE 57 bus system.

	SCA (proposed)	BBO [41]	DE[41]	KHA[41]	OKHA[41]
Active power injected by UPFC (p.u.)					
Sending end	0.0765	0.0340	0.0718	0.0483	0.0664
Receiving end	0.0675	0.0387	0.0699	0.0518	0.0684
Reactive power injected by UPFC (p.u.)					
Sending end	0.0187	0.0317	0.0813	0.0347	0.0196
Receiving end	0.0065	0.0293	0.0545	0.0303	0.0082
Optimal location and parameters of UPFC					
Optimal position	12-16	12-17	19-20	12-17	12-16
Series source voltage (rad)	0.0543	0.0359	0.0611	0.0238	0.0529
Series source phase angle (rad)	0.1432	0.0128	0.0106	0.0333	0.1320
Shunt source voltage (p.u.)	1.0232	1.0362	1.0271	1.0316	1.0118
Shunt source phase angle (rad)	0.0675	0.0916	0.0754	0.0551	0.0782
Loss (MW)	39.098	41.3703	41.7006	41.0127	40.7324
Voltage deviation (p.u.)	0.0314	1.2117	1.2067	0.9875	0.0328
Computational time (s)	3.987	18.0723	14.8143	4.6327	4.1710

A comparison is made among the best compromise solution obtained from the proposed SCA method and the solutions obtained by BBO, DE, KHA and OKH algorithms. The results of this comparison are shown in Table 4 and 5. As it is shown in Table 5, the results achieved from the presented SCA method for the best transmission loss and voltage deviation are significantly reduced to those of the BBO, DE, KHA and OKHA algorithms which demonstrates the reliability of the SCA algorithm.

6.2. Test System 2: 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 77 dimensions, that is, the 54 generator buses, 64 load buses, 186 transmission lines, 9 transformer taps and 14 reactive power sources. 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 6 respectively. The voltage limits of the series sources of the UPFC are taken as 0–0.2 p.u. and the lower and upper limits of the shunt voltage sources of the UPFC are 0 p.u. and 1.1 p.u., respectively. The phase angles of both series and shunt sources are within the range of 0–2p. The shunt and series impedances of installed UPFC are taken as $(0.01 + j0.1)$ p.u. and $(0.001 + j0.2)$ p.u., respectively. The system loads are given as follows $P_{load} = 4242$ MW, $Q_{load} = 1438$ MVar.

Table 6. 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				

Optimal Reactive Power Dispatch with Series and Shunt Facts Devices using Sine Cosine Algorithm

Table 7. Best control variables settings for IEEE-118 bus system

Control variables	<i>SCA (proposed)</i>	<i>BBO [41]</i>	<i>DE[41]</i>	<i>KHA[41]</i>	<i>OKHA[41]</i>
V ₁ (pu)	1.0125	0.9944	1.0014	1.0022	0.9944
V ₄ (pu)	1.0133	1.0223	1.0160	1.0311	1.0244
V ₆ (pu)	1.0105	0.9918	0.9955	1.0006	1.0108
V ₈ (pu)	1.0078	1.0169	0.9532	1.0067	1.0855
V ₁₀ (pu)	1.0067	0.9791	1.0202	1.0775	1.0998
V ₁₂ (pu)	1.0082	1.0037	1.0264	1.0004	1.0091
V ₁₅ (pu)	1.0113	0.9747	1.0096	1.0302	1.0198
V ₁₈ (pu)	1.0118	0.9952	1.0302	1.0388	1.0168
V ₁₉ (pu)	1.0125	1.0102	1.0297	1.0145	1.0155
V ₂₄ (pu)	1.0076	1.0602	1.0012	1.0260	1.0338
V ₂₅ (pu)	1.0031	1.0154	1.0767	1.0834	1.0937
V ₂₆ (pu)	1.0134	1.0106	1.0055	1.0437	1.0977
V ₂₇ (pu)	1.0117	1.0293	0.9764	1.0104	1.0430
V ₃₁ (pu)	1.0123	0.9936	1.0023	0.9865	1.0238
V ₃₂ (pu)	1.0121	0.9865	1.0224	1.0155	1.0343
V ₃₄ (pu)	1.0135	1.0288	1.0458	1.0118	1.0136
V ₃₆ (pu)	1.0137	0.9804	0.9961	1.0043	1.0081
V ₄₀ (pu)	1.0101	1.0186	1.0126	1.0032	1.0065
V ₄₂ (pu)	1.0116	0.9725	1.0076	1.0306	1.0185
V ₄₆ (pu)	1.0143	1.0117	1.0161	1.0413	1.0355
V ₄₉ (pu)	1.0105	1.0060	1.0040	1.0053	1.0457
V ₅₄ (pu)	1.0106	1.0153	0.9972	1.0287	1.0090
V ₅₅ (pu)	1.0125	1.0581	0.9901	1.0213	1.0149
V ₅₆ (pu)	1.0112	1.0381	1.0130	1.0212	1.0128
V ₅₉ (pu)	1.0114	1.0572	1.0130	1.0176	1.0300
V ₆₁ (pu)	1.0127	0.9726	0.9998	0.9940	1.0078
V ₆₂ (pu)	1.0135	0.9757	1.0187	0.9755	1.0193
V ₆₅ (pu)	1.0121	0.9931	0.9612	1.0202	1.0637
V ₆₆ (pu)	1.0136	1.0366	1.0078	1.0383	1.0629
V ₆₉ (pu)	1.0113	1.0452	0.9836	1.0472	1.0621
V ₇₀ (pu)	1.0150	0.9853	1.0418	1.0302	1.0178
V ₇₂ (pu)	1.0105	0.9528	1.0120	1.0236	1.0165
V ₇₃ (pu)	1.0134	1.0137	0.9761	0.9579	1.0161
V ₇₄ (pu)	1.0073	0.9603	1.0065	0.9829	1.0052
V ₇₆ (pu)	1.0131	1.0323	1.0462	1.0264	0.9893
V ₇₇ (pu)	1.0121	1.0193	1.0171	1.0006	1.0068
V ₈₀ (pu)	1.0118	1.0416	1.0279	1.0355	1.0267
V ₈₅ (pu)	1.0104	1.0092	1.0399	1.0285	1.0451
V ₈₇ (pu)	1.0124	1.0005	1.0066	0.9964	1.0263
V ₈₉ (pu)	1.0131	1.0155	1.0163	1.0422	1.0955
V ₉₀ (pu)	1.0123	1.0484	0.9507	1.0441	1.0662
V ₉₁ (pu)	1.0117	1.0085	0.9939	1.0113	1.0603
V ₉₂ (pu)	1.0115	0.9929	1.0379	1.0271	1.0708
V ₉₉ (pu)	1.0129	0.9589	1.0623	1.0335	1.0572
V ₁₀₀ (pu)	1.0135	1.0353	1.0393	1.0316	1.0717
V ₁₀₃ (pu)	1.0095	1.0298	1.0493	1.0514	1.0715
V ₁₀₄ (pu)	1.0120	1.0322	1.0909	1.0121	1.0712
V ₁₀₅ (pu)	1.0134	1.0120	1.0108	0.9901	1.0639
V ₁₀₇ (pu)	1.0090	1.0151	1.0688	1.0350	1.0470
V ₁₁₀ (pu)	1.0131	0.9923	0.9845	1.0076	1.0617
V ₁₁₁ (pu)	1.0131	1.0335	0.9548	1.0505	1.0643
V ₁₁₂ (pu)	1.0100	0.9665	1.0482	0.9990	1.0565
V ₁₁₃ (pu)	1.0094	1.0169	0.9997	1.0167	1.0459
V ₁₁₆ (pu)	1.0127	0.9637	1.0182	0.9655	1.0435
T ₅₋₈	0.9984	1.0374	1.0238	1.0667	1.0864
T ₂₅₋₂₆	1.0014	0.9460	1.0712	0.9111	1.0224
T ₁₇₋₃₀	0.9965	0.9608	1.0004	1.0491	1.0192
T ₃₇₋₃₈	0.9949	0.9717	0.9654	0.9101	0.9696
T ₅₉₋₆₃	0.9969	1.0211	1.0663	1.0328	1.0315
T ₆₁₋₆₄	0.9751	0.9799	1.0715	0.9469	1.0253

T_{65-66}	0.9856	0.9436	0.9088	0.9549	0.9274
T_{68-69}	1.0010	0.9184	0.9454	0.9218	1.0076
T_{80-81}	0.9983	0.9637	1.0182	0.9655	1.0435
Q_{c5} (pu)	0.0888	0.1246	0.2359	0.2282	0.0988
Q_{c34} (pu)	0.0127	0.0056	0.0369	0.0211	0.0027
Q_{c37} (pu)	0.0154	0.1669	0.0685	0.1209	0.0264
Q_{c44} (pu)	0.0780	0.0747	0.0574	0.0691	0.0790
Q_{c45} (pu)	0.0968	0.0300	0.0725	0.0901	0.0868
Q_{c46} (pu)	0.0894	0.0285	0.0765	0.0613	0.0784
Q_{c48} (pu)	0.0024	0.0313	0.0286	0.0070	0.0037
Q_{c74} (pu)	0.0205	0.0050	0.0239	0.0749	0.0204
Q_{c79} (pu)	0.1807	0.1214	0.1392	0.1379	0.1907
Q_{c82} (pu)	0.1720	0.1633	0.1284	0.1812	0.1910
Q_{c83} (pu)	0.0580	0.0874	0.0004	0.0693	0.0610
Q_{c105} (pu)	0.1243	0.1791	0.1602	0.1595	0.1143
Q_{c107} (pu)	0.0086	0.0036	0.0273	0.0036	0.0066
Q_{c110} (pu)	0.0013	0.0201	0.0143	0.0400	0.0032

Table 8. Best solutions of all algorithms for IEEE 118 bus system.

	SCA (proposed)	BBO [41]	DE[41]	KHA[41]	OKHA[41]
Active power injected by UPFC (p.u.)					
Sending end	0.0265	0.0238	0.0417	0.0182	0.0295
Receiving end	0.0275	0.0226	0.0429	0.0211	0.0284
Reactive power injected by UPFC (p.u.)					
Sending end	0.0287	0.0316	0.0206	0.0344	0.0267
Receiving end	0.0165	0.0284	0.0137	0.0224	0.0230
Optimal location and parameters of UPFC					
Optimal position	51-58	49-54	50-57	56-58	50-57
Series source voltage (rad)	0.0533	0.0583	0.0982	0.0643	0.0695
Series source phase angle (rad)	0.0432	0.0828	0.1042	0.0837	0.0571
Shunt source voltage (p.u.)	1.0532	1.0346	1.0283	1.0498	1.0428
Shunt source phase angle (rad)	0.0275	0.1221	0.1006	0.0672	0.0390
Loss (MW)	185.987	194.3421	197.0782	192.6608	190.3824
Voltage deviation (p.u.)	1.1877	1.2842	1.3018	1.2715	1.1944
Computational time (s)	7.987	22.8240	19.7211	8.3772	8.3069

In order to validate the effectiveness of the proposed procedure for multi-objective problem, it is applied on IEEE 118-bus system to minimize the transmission loss and voltage deviation simultaneously. To validate the superiority, the proposed SCA method is compared with the BBO, DE, KHA and OKHA algorithms. The optimal control variable settings, transmission loss and voltage deviation obtained using various intelligent techniques are given in Table 7. It can be seen from Table 7 that the proposed SCA technique gives the best compromising solutions among all the techniques without violating any operating constraint limits. Moreover, for minimizing the real power losses and voltage deviation further, a UPFC device is optimally placed on IEEE 118-bus system by the presented approaches. Results obtained by the proposed SCA method are compared with OKHA, KHA, BBO and DE methods which are summarized in Table 8. The simulation results clearly show that the best compromising transmission loss and voltage deviation obtained by the proposed SCA approach is least compared with other methods which emphasizes its better solution quality.

7. CONCLUSION

In the proposed work, Sine Cosine optimization algorithm is applied for effective co-ordination of UPFC device with the control variables present in a connected power system. To obtain reactive power optimization with FACTS devices, the implementation of sine cosine algorithm has been carried out on the IEEE 57-bus, and large 118-bus systems. SCA was one among various optimization methods that produces better results 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 considered as a very good optimization technique in the area of power system planning and future research credentials.

REFERENCES

- [1] Dommel, H. W. and Tinney, W. F., Optimal Power Flow Solutions. IEEE Transactions on Power Apparatus and Systems, 1968, 87, 1866–1876.
- [2] Venikov, V A Cybernetics in Electrical Power Systems, M I R Publishers, Moscow, 1978.
- [3] Mamandur, K R C and Chenoweth, R D 'Optimal Control for Reactive Power Flow for Improvements in Voltage Profiles and for Real Power Losses Minimization', IEEE Transactions on Power Apparatus and Systems PAS-100 (1981) pp 3185-3193.
- [4] Deeb N, Shahedipour SM. Linear Reactive Power Optimization in a Large Power Network Using the Decomposition Approach. In: IEEE Tran Power Syst, vol. 5, no. 2; 1990. p. 428–35.
- [5] Momoh JA, El-Hawary ME, Adapa R. A Review of Selected Optimal Power Flow Literature to 1993. II. Newton, Linear Programming And Interior Point Methods. IEEE Trans Power Syst 1999;14(1):105–11.
- [6] Granville S. Optimal Reactive Dispatch through Interior Point Methods. In: IEEE trans power syst, vol. 9, no. 1; 1994. p. 136–46.
- [7] Momoh JA, Adapa R, El-Hawary ME. A Review of Selected Optimal Power Flow Literature to 1993. I. Nonlinear and Quadratic Programming Approaches. IEEE Trans Power Syst 1999;14(1):96–104.
- [8] Yan, W., Lu, S., Yu, D.C., 2004. A Novel Optimal Reactive Power Dispatch Method Based on an Improved Hybrid Evolutionary Programming Technique. IEEE Trans. Power Syst. 19 (2), 913-918.
- [9] Zhao, B., Guo, C.X., Cao, Y.J., 2005. A Multi-Agent-Based Particle Swarm Optimization Approach For Optimal Reactive Power Dispatch. IEEE Trans. Power Syst. 20 (2), 1070-1078.
- [10] Varadarajan, M., Swarup, K.S., 2008. Differential Evolution Approach for Optimal Reactive Power Dispatch. Applied Soft Computing, 8(4), September 2008, 1549-1561.
- [11] Ying Li, Yijia Cao, Zhaoyan Liu, Yi Liu, Quanyuan Jiang., 2009. Dynamic optimal reactive power dispatch based on parallel particle swarm optimization algorithm. Computers and Mathematics with Applications, 57, 1835-1842.
- [12] Chaohua Daia, Weirong Chen, Yunfang Zhu, Xuexia Zhang., 2009. Reactive Power Dispatch Considering Voltage Stability with Seeker Optimization Algorithm. Electric Power Systems Research, 79, 1462–1471.
- [13] K. Mahadevan, P.S. Kannan., 2010. Comprehensive Learning Particle Swarm Optimization for Reactive Power Dispatch. Applied Soft Computing, 10, 641–652.

- [14] Xuexia Zhang, Weirong Chen, Chaohua Dai, Wenzhao Cai., 2010. Dynamic Multi-Group Self-Adaptive Differential Evolution Algorithm for Reactive Power Optimization. *Electrical Power and Energy Systems*, 32, 351–357.
- [15] A.H. Khazali, M. Kalantar., 2011. Optimal Reactive Power Dispatch Based On Harmony Search Algorithm. *Electrical Power and Energy Systems*, 33, 684–692.
- [16] S. Jeyadevi, S. Baskar, C.K. Babulal, M. Willjuice Iruthayarajan, 2011. Solving Multiobjective Optimal Reactive Power Dispatch Using modified NSGA-II. *Electrical Power and Energy Systems*, 33, 219–228.
- [17] Roy, P.K., Mandal, B., Bhattacharya, K., 2012. Gravitational Search Algorithm Based Optimal Reactive Power Dispatch For Voltage Stability Enhancement. *Electr. Power Compon. Syst* 40 (9), 956-976.
- [18] Xu, Y., Zhang, W., Liu, W., Ferrese, F., 2012. Multiagent-Based Reinforcement Learning for Optimal Reactive Power Dispatch. *IEEE Trans. Syst. Man Cybern. Part B Cybern.* 42 (6), 1742-1751.
- [19] S. Duman., Y. Sonmez., U. Guvenc. , N. Yorukeren, 2012. Optimal Reactive Power Dispatch Using a Gravitational Search Algorithm. *IET Gener. Transm. Distrib.*, Vol. 6, Iss. 6, pp. 563–576
- [20] R. Mallipeddi, S. Jeyadevi, P.N. Suganthan, S. Baskar, 2012. Efficient Constraint Handling for Optimal Reactive Power Dispatch Problems. *Electrical Power and Energy Systems*, 5, 28–36.
- [21] Barun Mandal, Provas Kumar Roy, 2013. Optimal Reactive Power Dispatch Using Quasi-Oppositional Teaching Learning Based Optimization. *Electrical Power and Energy Systems*, 53, 123–134.
- [22] Barun Mandal, Provas Kumar Roy, 2013. Multi-Objective Optimal Reactive Power Dispatch Considering Voltage Stability in Power Systems using HFMOEA. *Engineering Applications of Artificial Intelligence*, 26, 390–404.
- [23] Mojtaba Ghasemi, Sahand Ghavidel, Mohammad Mehdi Ghanbarian, Amir Habibi, 2014. A New Hybrid Algorithm for Optimal Reactive Power Dispatch Problem with Discrete And Continuous Control Variables. *Applied Soft Computing* 22, 126–140.
- [24] Binod Shaw, V. Mukherjee, S.P. Ghoshal, 2014. Solution of Reactive Power Dispatch of Power Systems by an Opposition-Based Gravitational Search Algorithm. *Electrical Power and Energy Systems*, 55, 29–40.
- [25] Abhishek Rajan, T. Malakar, 2015. Optimal Reactive Power Dispatch Using Hybrid Nelder-Mead Simplex Based Firefly Algorithm. *Electrical Power and Energy Systems*, 66, 9–24.
- [26] Mojtaba Ghasemi, Mahdi Taghizadeh, Sahand Ghavidel, Jamshid Aghaei, Abbas Abbasian, 2015. Solving Optimal Reactive Power Dispatch Problem Using a Novel Teaching-Learning-Based Optimization Algorithm. *Electrical Power and Energy Systems*, 39, 100–108.
- [27] Mehdi Mehdinejad, Behnam Mohammadi-Ivatloo, Reza Dadashzadeh-Bonab, Kazem Zare, 2016. Solution of Optimal Reactive Power Dispatch of Power Systems Using Hybrid Particle Swarm Optimization and Imperialist Competitive Algorithms. *Electrical Power and Energy Systems*, 83, 104–116.
- [28] Chandragupta Mauryan Kuppamuthu Sivalingam, Subramanian Ramachandran, Purnimaa Shiva Sakthi Rajamani, 2017. Reactive Power Optimization In A Power System Network Through Metaheuristic Algorithms. *Turk J Elec Eng & Comp Sci*, 25, 4615-4623.

Optimal Reactive Power Dispatch with Series and Shunt Facts Devices using Sine Cosine Algorithm

- [29] Kasem Nuaekaew, PraminArtrit, Nantiwat Pholdee, Sujin Bureerat, 2017. Optimal Reactive Power Dispatch Problem Using A Two-Archive Multi-Objective Grey Wolf Optimizer. *Expert Systems with Applications*, 87(30), 79-89.
- [30] Xiaoshun Zhang, Tao Yu, Bo Yang, Lefeng Cheng, 2017. Accelerating Bio-Inspired Optimizer with Transfer Reinforcement Learning for Reactive Power Optimization. *Knowledge-Based Systems*, 116, 26–38.
- [31] Khaled ben oualid Medania, Samir Sayaha Abdelghani Bekrarb, 2018. Whale Optimization Algorithm Based Optimal Reactive Power Dispatch: A case study of the Algerian Power System. *Electric Power Systems Research*, 163, Part B, 696-705.
- [32] SK. Mahammad Shareef, R. Srinivasa Rao, 2018. Optimal Reactive Power Dispatch Under Unbalanced Conditions Using Hybrid Swarm Intelligence. *Computers and Electrical Engineering*, 69, 183–193.
- [33] Hotaka Yoshida, Yoshikazu Fukuyama, 2018. Parallel Multipopulation Differential Evolutionary Particle Swarm Optimization for Voltage and Reactive Power Control. *Electrical Engineering in Japan*, Vol. 204, No. 3, 31-40.
- [34] Mirjalili S. SCA: A Sine Cosine Algorithm for Solving Optimization Problems. *Knowledge Based Systems* 2016; 96:120–33.
- [35] D. Karthikaikannan, G. Ravi, 2018. Optimal Reactive Power Dispatch Considering Multi-Type FACTS Devices Using Harmony Search Algorithms, *Automatika*, 59:3, 303-314.
- [36] Hingorani NG. High Power Electronics and Flexible AC Transmission System. *IEEE Power Eng Rev* 1998
- [37] Padhy NP, Abdel Moamen MA. Power Flow Control and Solutions With Multiple and Multi-Type FACTS Devices. *Electric Power Syst Res* 2005; EPSR-74. 341-35.
- [38] Ghahremani E, Kamwa I. Optimal Placement of Multiple-Type FACTS Devices to Maximize Power System Loadability using a Generic Graphical user Interface. *IEEE Trans Power Syst* 2013;28(2):764-78
- [39] MATLAB Release R2015b. Natick (MA, USA): The Mathworks Inc.
- [40] Zimmerman RD, Murillo-S´anchez CE. MATPOWER, a MATLAB Power System Simulation Package.<<http://www.pserc.cornell.edu/matpower/manual.pdf> >; September 2007.
- [41] Susanta Dutta, Pranabesh Mukhopadhyay, Provas Kumar Roy, Debashis Nandi, 2016. Unified Power Flow Controller Based Reactive Power Dispatch Using Oppositional Krill Herd Algorithm. *Electrical Power and Energy Systems*, 80, 10–25.
- [42] Sarabjeet Singh, Satvir Singhand Vijay Kumar Banga, GPU Based Toolbox for Fuzzy Logic System using Whale Optimization Algorithm. *International Journal of Computer Engineering and Technology*, 10(1), 2019, pp. 11-24
- [43] Smitkumar Choudante and A.A. Bhole, Comparision of Voltage Stability and Power Flow Improvement by using Different Facts Devices: *International Journal of Electrical Engineering & Technology*, 9(4), 2018, pp. 144–153
- [44] Radhakrishna K R, Dr. T Ananthapadmanabha, Likith Kumar M V and R. Chidanandappa, Minimization of Losses in Distribution System with D-Facts Devices. *International Journal of Electrical Engineering & Technology*, 7(4), 2016, pp. 1–15