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# Optimal Siting and Sizing of SSSC Using Modified Salp Swarm Algorithm Considering Optimal Reactive Power Dispatch Problem

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**ABSTRACT** The Flexible alternating current transmission systems (FACTS) is considered one of the most developed technologies applied for enhancing the performance of system due to their ability of adjusting different parameters in the transmission systems such as the buses voltage, the transmission line impedance, the active and reactive powers flow in transmission lines. The static synchronous series compensator (SSSC) is an effective member of the FACTS which is connected in series with the transmission lines and it consists of a solid-state voltage source inverter coupled with a transformer which aims to control and secure the operation of the power system. The main function of SSSC is inserting a controllable voltage in series with the transmission line to control the active and reactive powers flow in transmission lines. Solving the optimal reactive power dispatch (ORPD) problem is nonlinear, non-convex and it becomes a complex problem with integration of the SSSC. The contributions of article include, 1) an efficient and reliable optimization algorithm is developed to solve the ORPD problem and identify the optimal location and ratings of the SSSC, 2) The proposed algorithm is based on modifying the salp swarm algorithm (SSSA) using Levy Flight Distribution and spiral movement of particles to enhance the searching capabilities of the SSA, 3) an efficient model of SSSC based on power injection approach is used for representation the SSSC in ORPD. The ORPD is solved with and without the SSSC controller to minimize power losses and voltage deviations as well as improve the voltage stability. The proposed algorithm for ORPD is tested on the standards IEEE 30-bus and 57-bus systems. The simulation results demonstrate that MSSA is more effective and superior for solving the ORPD compared with some other reported meta-heuristic techniques. Moreover, the system performance is enhanced considerably with optimal inclusion the SSSC.

**INDEX TERMS** Optimal reactive power dispatch, static synchronous series compensator, flexible alternating current transmission systems.

## NOMENCLATURE

$P_G$  : Generator active power output

$V_G$  : Voltage of generation bus

$Q_c$  : Reactive power of shunt compensator

$T$  : Transformer taps

$N_G$  : Generators number

$N_c$  : Number of shunt compensator units

$P_{sp}$  : Specified active power

$Q_{sp}$  : Specified reactive power

$L_c$  : SSSC location

$P_{G1}$  : Slack bus power

$V_L$  : Voltage of load bus

$Q_G$  : Generator reactive power output

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$S_{TL}$	:	Apparent power flow in transmission line
$NPQ$	:	Load buses number
$NG$	:	Generation buses number
$N_{TL}$	:	Transmission lines number
$ V_{se} , \theta_{se}$	:	Voltage mag, phase angle of SSSC injected voltage
$P_{Gi}, P_{Di}$	:	Generated active and load demand power at bus $i$
$Q_{Gi}, Q_{Di}$	:	Generated active and load demand power at bus $i$
$ Y_{ij} , \theta_{ij}$	:	Admittance matrix magnitude and phase
$z_n^1$	:	Leader position
$Q_n$	:	Food source position
$u_n, l_n$	:	Upper, lower limits in $n^{\text{th}}$ dimension of search space
$r_1, r_2, r_3$	:	Random variables interval [0,1]
$e_G, e_Q, e_V, e_S, e_F, e_I$	:	Penalty factors

## I. INTRODUCTION

### A. GENERAL

In electric power system, the power flow intentions can be deliberated as fundamental of power scheme network calculations, since they are the most frequently accomplished program of power network designs which can be used in power scheme scheduling, operational forecasting, as well as operation/control. The optimal reactive power dispatch (ORPD) problem is a non-linear optimization problem related to optimal power flow. Solving the ORPD problem turns into a determined task in order to modify the power scheme for its secure and economical operation. The foremost aim to solve the ORPD problem is assigning the best operating set of control variables like voltages of the generators, transformer taps and the shunt compensator with satisfying operating constraints of the electric scheme [1]. The control variables remain enhanced for a definite fitness function. For example, boosting voltage stability as well as minimizing power losses and voltage deviation minimization.

### B. LITERATURE SURVEY

The ORPD problem has been solved with different conventional techniques, for example, linear and non-linear programming, interior point method as well as the quadratic programming [2]–[5]. The foremost disadvantage of the conventional techniques is difficult to be implement with non-convex or nonlinear fitness functions. Moreover, these techniques can confine proceeding local minima of the objective functions.

Newly, numerous meta-heuristic optimization techniques have been applied to solve the optimization problem. These methods not only have been confirmed to overcome the foremost shortcomings in conventional methods but also are efficaciously applied to solve the ORPD problem for example particle swarm optimization (PSO) [6], genetic algorithm

(GA) [7], whale optimization algorithm (WOA) [8], ant colony algorithm (ACA) [9], gravitational search algorithm (GSA) [10], lightning attachment procedure optimization [11], grey wolf optimization [12] and the conventional salp swarm algorithm [13].

In recent years, several available technologies have been produced and embedded in electric system to enhance their performance. FACTS are considered one of the most applied technology in electrical power systems to control different variables for example, the bus voltage magnitude, the active power, the reactive power, and the transmission line impedance. Therefore, the FACTS devices can enhance the security and stability of the power systems [14], [15]. Though, the foremost determination of ORPD problem is defining the control variables designed for the voltage profile enhancement, voltage stability improvement and power losses minimization. But it should be pointed out that solving the ORPD with incorporating the SSSC compensator in power system might considerably improve the performance of the system.

Although, the detail of FACTS is the submission of power electronic equipment in ways that regulate and control the electrical constraints through one or several functions to direct the operation of transmission schemes comprising voltage, current, impedance, phase angle and damping of oscillations [16]. FACTS controllers can cause quick alterations of the important scheme. Consequently, that can be able to considerably disturb the operation of traditional distance arrangements while moreover series or shunt connected FACTS devices present novel dynamic controls into the power schemes [43], [44]. They would predictably touch the features of a defensive relay in a transmission line towards approximately range.

The Static Synchronous Series Compensator (SSSC) controller is an elegant member of FACTS and it is inserted in series through transmission lines to control proceeding the active and reactive powers flow over transmission lines individually or instantaneously. SSSC provides the required controllability through inserting an AC voltage with well-regulated magnitude as well as phase angle in series with the transmission line [17], [18]. Ahmed *et al.* [19] discussed the ORPD problem considering SSSC on IEEE30 bus-system to improve the voltage profile with enhancing voltage stability using GWO. Marouani *et al.* [20] used multi-objective evolutionary algorithm (MOEA) for ORPD problem considering SSSC on 6 bus-system to minimize the real power losses with voltage deviation. Susanta *et al.* [21] solved ORPD problem by using chemical reaction optimization (CRO) using SSSC to minimize power losses of IEEE30 and IEEE57 bus-system. Mohamed, *et al.* [22] used improved harmony search algorithm considering SSSC in non-smooth cost functions on IEEE 30-bus system.

The novel nature inspired SSA is a simple and efficient optimization technique which simulate the swarm behavior of salps in nature and contains the iterative nature. Hence, it iteratively evolves and generates few random individuals

salps inside the search space. Then entire salps update their location, the leader salp attack in direction of food while followers move towards the rest of salps [29]. Some of related applications of SSA used in various fields, such as feature selection [23], tuning of power system stabilizer [24], PID-fuzzy control seismic excited structural system against earthquake [25], fuel cell [26], machine learning [27] and etc. However, SSA has some limitations and is faced with premature convergence in some cases [28].

**C. CONTRIBUTION TO THE RESEARCH**

The aim of the research is to identify the size and the optimal location of SSSC controllers in the power systems using novel modified Salp Swarm Optimization (MSSA). A simple SSSC model is developed with ORPD solution to optimize the power losses and voltage deviations reduction as well as the voltage stability boosting on IEEE 30-bus and IEEE 57-bus systems.

This research is organized in different sections such as; Section II represents the simple modelling and formulation of SSSC, Section III defines the ORPD formulation, Section IV defines methodology of the conventional SSA and MSSA with their graphical abstract and pseudo code, Section V demonstrates the results and discussion, Section VI defines the main achievements while Section VII is the part of conclusion.

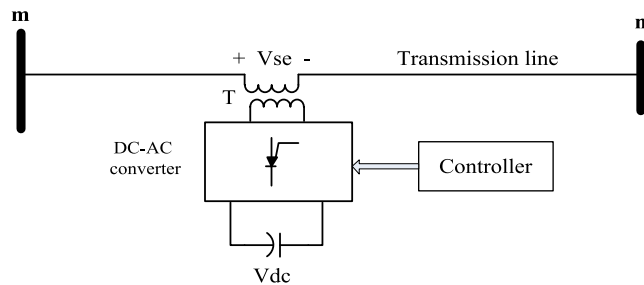


FIGURE 1. Schematic diagram of SSSC.

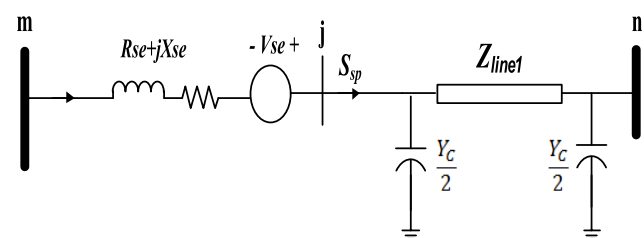


FIGURE 2. Equivalent circuit of SSSC.

**II. SSSC MODELS FORMULATION**

The SSSC consists, voltage source converter which is linked to a common DC and depicted in the Fig. 1. While Fig.2 illustrates the SSSC equivalent circuit where the voltage source

( $V_{se}$ ) is connected in series with the coupling transformer’s impedance ( $Z_{se}$ ).

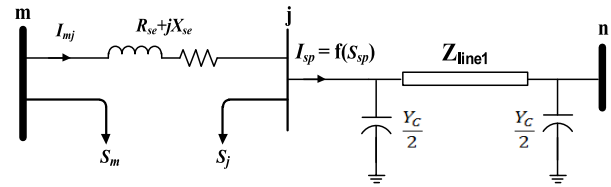


FIGURE 3. SSSC simplified model.

In Fig. 3, the simple model of SSSC is generally obtained by altering the voltage source  $V_{se}$  into the current source  $I_{inj}$  in parallel with impedance  $Z_{se}$ . The related discussion related current source the formulation is given as follow:

$$I_{inj} = \frac{V_{se}}{Z_{se}} = \frac{V_{se}}{R_{se} + jX_{se}} \tag{1}$$

The current  $I_{inj}$  can be injected at bus  $m$  and  $j$ . So, the new injected currents  $I_{inj}$  can be computed as the function of specified active and reactive power flow of the transmission line by applying the concept of Kirchoff current law at bus  $j$ .

$$I_{inj} = I_{sp} - I_{mj} = \left(\frac{S_{sp}}{V_j}\right)^* - \left(\frac{V_m - V_j}{R_{se} + jX_{se}}\right) \tag{2}$$

where,  $S_{sp}$  is depend on sum of  $P_{sp} + jQ_{sp}$ .  $I_{inj}$  can also be injected as the complex loads at  $m$  and  $j$  buses, as shown in Fig. 3, as written as follows:

$$S_m = V_m (I_{inj})^* \tag{3}$$

$$S_j = -V_j (I_{inj})^* \tag{4}$$

**III. ORPD PROBLEM FORMULATION FOR DIFFERENT OBJECTIVE FUNCTIONS**

**A. MINIMAZATION OF OBJECTIVE FUNCTIONS**

The optimal reactive power dispatch (ORPD) problem is generally formulated as:

$$MinF(x) \tag{5}$$

Subject to

$$g_j(x, u) = 0 \quad j = 1, 2, \dots, m \tag{6}$$

$$h_j(x, u) \leq 0 \quad j = 1, 2, \dots, p \tag{7}$$

where,  $F$  denotes the objective function,  $x$  and  $u$  represent the dependent and independent control variables,  $g_j$  and  $h_j$  are the equality and inequality constraints, while  $m$  and  $p$  are the number of equality and inequality constraints, respectively.

The independent variables can be represented as follows:

$$u = [P_{G2} \dots P_{GNG}, V_{G1} \dots V_{GNG}, Q_{C1} \dots Q_{CNC}, T_1 \dots T_{NT}, P_{sp}, Q_{sp}, L_c] \tag{8}$$

The dependent variables which include the generated power at slack bus, the voltages of the PQ buses, the generated reactive powers of the generators, the power flow in transmission

lines, the magnitude and the angle of the injected voltage by the SSSC. The dependent variables can be indicted as follows:

$$x = [P_{G1}, V_{L1} \dots V_{LN PQ}, Q_{G1} \dots Q_{GN G}, S_{TL1} \dots S_{TL NTL}, |V_{se}|, \theta_{se}] \quad (9)$$

1) MINIMAZATION OF POWER LOSSES

Generally, the minimization of active power losses be represented as:

$$F_1 = \sum_{i=1}^{NL} P_{losses} \quad (10)$$

2) MINIMAZATION OF VOLTAGE DEVIATIONS

The 2<sup>nd</sup> objective function is to reduce the voltage deviations (VD) and it is generally expression as follows:

$$F_2 = VD = \sum_{i=1}^{NL} [V_i - V_{ref}] \quad (11)$$

where, *NL* represents number of the transmission lines while *V<sub>ref</sub>* is reference voltage which commonly equals to 1.

3) ENCHANCEMENT OF VOLTAGE STABILITY

The 3<sup>rd</sup> objective function is to improve the voltage stability (*VSI*) which is proportional to the minimization of voltage stability indicator called *L*-index. This enhanced objective can be achieved by reducing the maximum value of the *L* index in the power networks

$$F_3 = L_i = \left| 1 - \sum_{j=1}^{N_g} Y_{ij} \frac{V_j}{V_i} \right|, \quad i = 1, 2, \dots, N_{BS} \quad (12)$$

where, *L<sub>i</sub>* represents the value of bus *i*, *Y<sub>ij</sub>* is the mutual admittance between bus *i* and *j*, while *N<sub>BS</sub>* represents the number of buses.

$$L = \max(L_i), \quad i = 1, 2, \dots, N_{BS} \quad (13)$$

**B. CONSTRAINTS**

1) EQUALITY CONSTRAINTS

These constraints represent the balanced load flow equations as:

$$P_{Gi} - P_{Di} = \sum_{j=1}^{NB} |V_i| |V_j| |Y_{ij}| \cos(\theta_{ij} - \delta_{ij})$$

$$Q_{Gi} - Q_{Di} = \sum_{j=1}^{NB} |V_i| |V_j| |Y_{ij}| \sin(\theta_{ij} - \delta_{ij}) \quad (14)$$

2) INEQUALITY CONSTRAINTS

These constraints which represent the operating limits of system components include:

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \quad i = 1, 2, \dots, NG \quad (15)$$

$$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max} \quad i = 1, 2, \dots, NG \quad (16)$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \quad i = 1, 2, \dots, NG \quad (17)$$

$$T_i^{min} \leq T_i \leq T_i^{max} \quad i = 1, 2, \dots, NT \quad (18)$$

$$Q_{Ci}^{min} \leq Q_{Ci} \leq Q_{Ci}^{max} \quad i = 1, 2, \dots, NC \quad (19)$$

$$S_{Li} \leq S_{Li}^{min} \quad i = 1, 2, \dots, NTL \quad (20)$$

$$V_{Li}^{min} \leq V_{Li} \leq V_{Li}^{max} \quad i = 1, 2, \dots, NPQ \quad (21)$$

$$V_{se}^{max} \leq V_{se} \leq V_{se}^{min} \quad (22)$$

$$\theta_{se}^{max} \leq \theta_{se} \leq \theta_{se}^{min} \quad (23)$$

The system constraints which added to the objective function are taken into consideration by using the penalty factors related the constraints. Thereby, the objective function can be formulated as:

$$F_g(x, u) = F_i(x, u) + e_G (P_{G1} - P_{G1}^{lim})^2$$

$$+ e_Q \sum_{i=1}^{NPV} (Q_{Gi} - Q_{Gi}^{lim})^2 + e_V \sum_{i=1}^{NPQ} (V_{Li} - V_{Li}^{lim})^2$$

$$+ e_S \sum_{i=1}^{NTL} (S_{Li} - S_{Li}^{lim})^2 + e_F (V_{se} - V_{se}^{lim})^2$$

$$+ e_t (\theta_{se} - \theta_{se}^{lim})^2 \quad (24)$$

**IV. METHODOLOGY**

It is worth mentioning that the salp swarm algorithm (SSA) is an efficient optimization technique and it has been wildly applied in several optimization problems. However, it suffers from stagnation and prone to local optima for some cases. Therefore, a modified slap swarm algorithm (MSSA) is proposed to render and overcome the shortages of the standard SSA. The proposed MSSA is based on implementing two searching strategies for enhancing its searching capability. The first strategy is applying Levy Flight Distribution (LFD) for enhancing the exploration process which enables the populations to jump to new area. The second strategy is based on spiral motion of the populations around the best solution to enhance the exploitation process. The pseudocode of the conventional SSA and the modified MSSA are given in Algorithm I and II, while the graphical representation of MSSA to solve the ORPD problem using SSSC is given in Fig. 4.

**A. THE SALP SWARM ALGORITHM (SSA)**

The traditional SSA algorithm is the population based meta-heuristic introduced by Mirjalili in 2017 [29]. SSA simulates mechanism of swarm salps which will be scavenged in oceans. In ocean, the salp at the front of chain will be the leader while the remain salps will consider as the followers.

Likewise, other meta-heuristic approaches the position of the salp can be explain in *s* dimension, where *s* is the number of the variable for a given problem. Therefore, the positions of entire salps are keeping in a two-dimensional matrix called *z*. For example, in a search space there is a food source called *Q* and considered as the swarms' target. So, the expression of the SSA will be given as follows.

$$z_n^i = \begin{cases} Q_n + r_1 (u_n - u_n) r_2 + l_n r_3 \geq 0 \\ Q_n + r_1 (u_n - u_n) r_2 + l_n r_3 \leq 0 \end{cases} \quad (25)$$

where, *z<sub>n</sub><sup>i</sup>* and *Q<sub>n</sub>* represent the leader position and food source position, respectively. *u<sub>n</sub>* and *l<sub>n</sub>* are the upper and

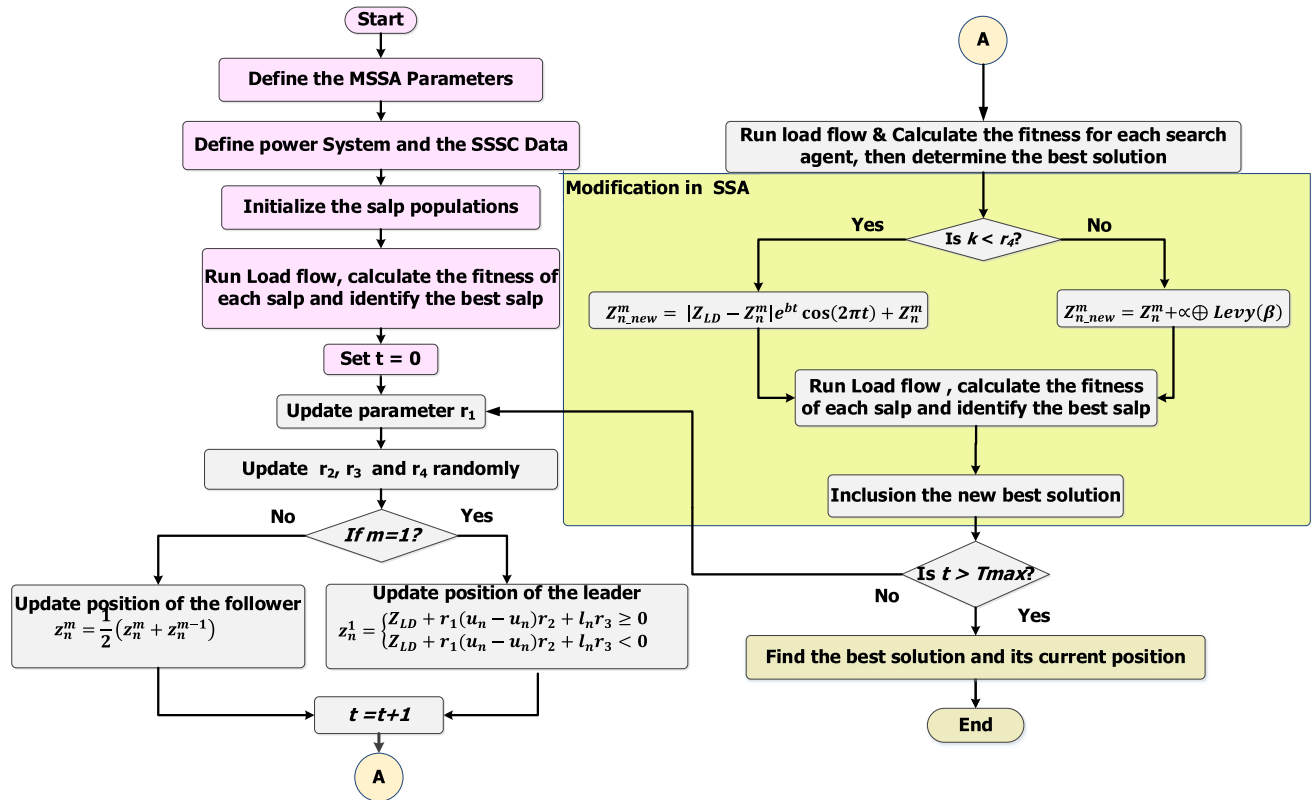


FIGURE 4. Graphical abstract of modified MSSA to solve ORPD problem with optimal inclusion of SSSC.

Algorithm 1 Pseudocode of Conventional SSA Algorithm

Start SSA

- Step (1) Set the parameters of SSA technique including maximum number of iteration ( $T_{max}$ ), number of populations, the upper and lower limits of the control variables
- Step (2) Initialize a population of (S) salps' position randomly
- Step (3) Run the load flow and calculate the fitness evaluation for each salp
- Step (4) Set iteration  $t = 1$
- Step (5) Update  $r_1$  according to Eq. (26)
- Step (6) For every salp
  - If  $m == 1$ , update position of leading salp by Eq. (25)
  - Otherwise, update position of follower salp by Eq. (28)
  - Fitness evaluation of every salp: Update ( $Z^*$ ), if there is a superior solution.
  - Increment  $t$  to 1.
  - Repeat steps 5 to 7 until ( $t = T_{max}$ ) is satisfied
- Step (7) Return the best solution ( $Z^*$ ) and its fitness value  $f(Z^*)$

End SSA

lower limits in  $n$ -th dimension of search space.

$$r_1 = 2e^{-\left(-\frac{4a}{A}\right)} \quad (26)$$

In order to change the position of followers, the following expression is used.

$$z_n^m = \frac{1}{2}ce^2 + v_oe \quad (27)$$

where,  $m \geq 2$ ,  $c = \frac{v_{final}}{v_o}$  and  $v = \frac{z-z_o}{e}$ . The simulation time is depending on the iterations and the conflict between iteration is equal to 1 while considering  $v_o = 0$ , the Equation (25) will be as followed.

$$z_n^m = \frac{1}{2}\left(z_n^m + z_n^{m-1}\right) \quad (28)$$

B. MODIFIED SALP SWARM ALGORITHM (MSSA)

The MSSA is proposed to overcome the shortages of the conventional SSA which include its tendency to local optima



**Algorithm 2** Pseudocode of Modified MSSA Algorithm

**Start MSSA**

**Step (1)** Set the parameters of MSSA technique including maximum number of iteration ( $T_{max}$ ), number of populations, the upper and lower limits of the control variables

**Step (2)** Initialize a population of ( $S$ ) salps' position randomly

**Step (3)** Run the load flow and calculate the Fitness evaluation for each salp

**Step (4)** Set iteration  $t = 1$

**Step (5)** Update  $r_1$  according to Eq. (26)

**Step (6)** For every salp

If  $mD = 1$ , update position of leading salp by Eq. (25)

Otherwise, update position of follower salp by Eq. (28)

Fitness evaluation of every salp: Update ( $Z^*$ ) if there is a superior solution.

**Step (7)** Sorting the salp based on their fitness values

**Step (8)** Update the  $k$  value according to Eq. (34).

**Step (9)** Compare the value of  $k$  with a random value  $r_4$ .

**If** the value of  $k$  is less than  $r_4$

Update the salp positions based on the spiral orientation according to Eq. (33)

**Else**

Update the salp positions based on Levy distribution according to Eq. (29)

**End**

**Step (10)** Calculate the fitness function of the updated salps. Then, include the new solutions if these solutions are better than the solutions of the previous steps

Increment  $t$  to  $1$ .

Repeat steps 5 to 7 until ( $t = T_{max}$ ) is satisfied

**Step (7)** Return the best solution ( $Z^*$ ) and its fitness value  $f(Z^*)$

**End MSSA**

and stagnation for some cases. Two search strategies are presented for enhancing capability of the conventional SSA. The first modification is utilized for boosting the exploration process by updating the locations of salps using the Levy flight distribution (LFD) to aid population to find new areas to overcome its stagnation. While the second modification depends upon modifying and updating the locations of salps in the spiral path around the best solution to enhance its exploitation. The first modification which based on the LFD is expressed as follows:

$$Z_{n\_new}^m = Z_n^m + \alpha \oplus Levy(\beta) \tag{29}$$

where  $\alpha$  refers to a step size parameter which is assigned as follows:

$$\alpha \oplus Levy(\beta) \sim 0.01 \frac{u}{|v|^{1/\beta}} (Z_n^m - Z_{LD}) \tag{30}$$

where  $u$  and  $v$  are determined using (29) and (30) as follows:

$$u \sim N(0, \phi_u^2), v \sim N(0, \phi_v^2) \tag{31}$$

$$\phi_u = \left[ \frac{\Gamma(1 + \beta) \times \sin(\pi \times \beta/2)}{\Gamma[(1 + \beta)/2] \times \beta} \right]^{1/\beta}, \phi_v = 1 \tag{32}$$

where  $\Gamma$  represents the standard gamma function. The second modification is based on modifying the locations of salps

in the spiral path around the best solution which can be expressed as follows:

$$Z_{n\_new}^m = |Z_{LD} - Z_n^m| e^{bt} \cos(2\pi t) + Z_n^m \tag{33}$$

where  $b$  denotes a constant to describe the logarithmic spiral shape. To balance the exploration and the exploitation process an adaptive operator  $k$  is utilized to achieve this task.

$$k(t) = k_{min} + \left( \frac{k_{max} - k_{min}}{T_{max}} \right) \times t \tag{34}$$

where,  $k_{max}$  and  $k_{min}$  are the maximum and the minimum  $k$  limits. Finally, it is worth mentioned that searching capability of the MSSA is improved by enhancing the exploration phase using the LFD by applying Eq. (27) at the first iteration when the value of  $k$  is small while the exploitation phase is enhanced using the variable bandwidth transition by applying Eq. (31) at the final iteration when the value of  $k$  is large.

**V. RESULTS AND DISCUSSION**

In order to demonstrate the effectiveness of proposed MSSA algorithm compared simple SSA, the simulation is run on MATLAB on Window 10 Professional Lenovo E-480 Model Intel®Core™i7-8550U CPU @ 1.80 GHz 8GB RAM. The ORPD problem is solved with optimal site and sizing of the

SSSC to minimize transmission line losses, voltage deviations and enhancing the voltage stability index.

The MSSA is employed to determine the parameters setting and location of SSSC controller. The proposed algorithm is tested on IEEE30 and IEEE57 standard bus systems and the simplified SSSC model is used to represent the SSSC into power flow solution. The data of system as well as the upper and the lower limits of the control variables are taken from [30], [31] and [32]. The voltage limits range of PQ buses between [0.95-1.05] p.u while the series injected voltages magnitude limits are between [0.001, 0.2] for SSSC. The system based on MVA is 100 while the penalty factors in Eq. (22) are set to 100. The selected parameters of the MSSA are listed Table 1.

**TABLE 1. Parameters Settings of MSSA Algorithm for IEEE 30 and 57 Bus Standards.**

Parameters Settings	IEEE 30	IEEE57
Population Size	25	25
$T_{max}$	100	100
Independent Runs	30	30
$k_{min}$	0.43	0.43
$k_{max}$	0.85	0.85

To better understand the article, the simulation outcomes of MSSA and conventional SSA for IEEE 30-bus and IEEE 57-bus systems are given into different cases with and without SSSC controller. The detail studied cases are presented as follows:

- *CASE I:* Solving the ORPD without inclusion the SSSC on IEEE30-bus system.
- *CASE II:* Solving the ORPD with optimal inclusion the SSSC on IEEE30-bus system.
- *CASE III:* Solving the ORPD without inclusion the SSSC on IEEE 57-bus system.
- *CASE IV:* Solving the ORPD with optimal inclusion the SSSC on 57-bus system.

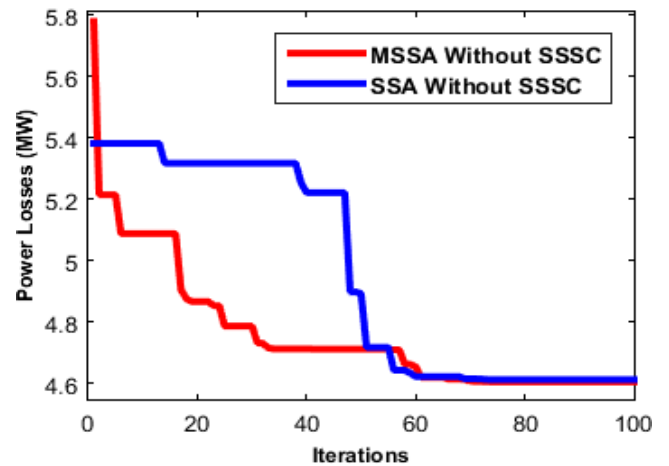
In case of comparison the results without using SSSC, the values of base case are considered such as 5.811 MW for IEEE 30-bus system and 27.86 MW for IEEE 57-bus system [42], respectively.

**A. CASE I: SOLVING THE ORPD WITHOUT INCLUSION THE SSSC ON IEEE30-BUS SYSTEM**

**1) MINIMAZATION OF POWER LOSSES**

In this case, MSSA and SSA techniques are applied for minimizing the power losses without optimal inclusion of SSSC controller. The selected of parameters of MSSA are given in the Table. 1. Fig. 5 shows the convergence plot of the power loss by applying the SSA and MSSA. Fig. 5 demonstrated that the better convergence response getting from the MSSA algorithm. The outcomes of MSSA and SSA including the best, the average, the worst, and the standard values with simulation time are given in Table. 2.

The best achieved value for this case by application of the MSSA is 4.5902 MW while the worst value reported



**FIGURE 5. Convergence Performance of MSSA and SSA for Power Losses (MW) Minimization Without Inclusion the SSSC on IEEE30 Bus-Standard.**

by SSA is 4.6137 MW. The MSSA’S best outcome is reported 0.51% less reported compared with conventional SSA. The best outcomes getting by MSSA and SSA techniques are further compared with the base case 5.811 MW which gives 21.01% and 20.60% less in reduction in power losses.

In addition, judging from table 3, the obtained power loss by MSSA is less than HSA [34], EP [33], SGA [34], AGA [35], PSO [34], CLPSO [35], DE [36], PG-PSO [40], FODPSO [37], FODPSO-EE [38], CAMES [39] and PSO-TVAC [40] BY 3.6158 %, 7.5116 %, 7.0960 %, 6.8169 %, 6.7771 %, 2.7665 %, 8.3975 %, 1.1265 %, 0.3430 %, 0.1501 %, 7.1749 %, and 5.2571 %, respectively. The optimal control values for this case are listed in APPENDIX. 1.

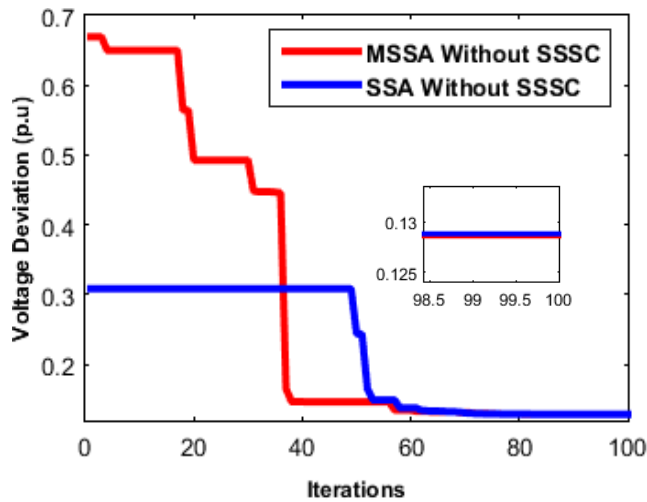
**2) MINIMAZATION OF VOLTAGE DEVIATIONS**

In this case, the simulation is run to minimize the voltage deviations (VD) by using the MSSA and SSA techniques without inclusion the SSSC controller. Fig. 6 illustrates the best convergence response getting by the MSSA algorithm over the conventional SSA. Table. 2 shows the best, average, worst, standard deviation, and the simulation time for minimization the VD.

The minimum VD that obtained by application of the MSSA and SSA are 0.1286 p.u. and 0.1288 p.u., respectively. In other words, the VD is reduced by 0.1553 % with application of the MSSA compared with the SSA. According to the comparisons in Table 3, the obtained VD by application of the MSSA is better than HSA [34], SGA [34], PSO [34], and PSO-TVAC [40] by 4.6701 %, 14.3238 %, 9.6910 %, and 37.6938 %, respectively. The optimal values of the control parameters for this case are tabulated in APPENDIX 2. Figure 6 shows the trends of the VD with application of the SSA and the MSSA, it is clear that the proposed algorithm has stable convergence characteristics.

**TABLE 2. Simulation Outcomes of MSSA and SSA Techniques With and Without Optimal Inclusion of SSSC Using IEEE 30-Bus Standard.**

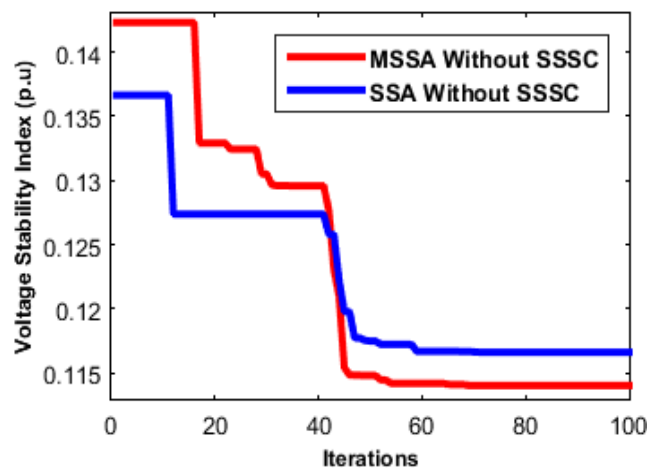
Power Losses (MW) With and Without SSSC for IEEE30 Bus Standard					
With SSSC					
Algorithm	Best	Average	Worst	Std	Time (sec)
SSA	4.4361	4.9578	5.5932	0.2686	23.8528s
MSSA (proposed)	4.3541	4.7213	5.3894	0.2074	22.6109s
Without SSSC					
Algorithm	Best	Average	Worst	Std	Time (sec)
SSA	4.6137	4.7761	5.1808	0.1562	3.8333s
MSSA (proposed)	4.5902	4.7178	4.8119	0.0571	6.7358s
Voltage Deviations (p.u) With and Without SSSC for IEEE30 Bus Standard					
With SSSC					
Algorithm	Best	Average	Worst	Std	Time (sec)
SSA	0.1279	0.1735	0.2516	0.0298	32.0559s
MSSA (proposed)	0.1160	0.1671	0.2157	0.0245	39.9856s
Without SSSC					
Algorithm	Best	Average	Worst	Std	Time (sec)
SSA	0.1288	0.1626	0.1983	0.0213	4.4205s
MSSA (proposed)	0.1286	0.1635	0.2093	0.021	6.7673s
Voltage Stability Index (p.u) With and Without SSSC for IEEE30 Bus Standard					
With SSSC					
Algorithm	Best	Average	Worst	Std	Time (sec)
SSA	0.0842	0.1071	0.119	0.0105	27.7836
MSSA (proposed)	0.0750	0.0943	0.11	0.0128	18.0927s
Without SSSC					
Algorithm	Best	Average	Worst	Std	Time (sec)
SSA	0.1166	0.1192	0.1224	0.0013	4.4672s
MSSA (proposed)	0.1140	0.1159	0.1206	0.0014	5.7277s



**FIGURE 6. Convergence performance of MSSA and SSA for minimizing the voltage deviation (p.u) without inclusion the SSSC on IEEE30 bus-standard.**

3) ENHANCEMENT OF VOLTAGE STABILITY

In this case, the simulation is run by MSSA and SSA techniques for the enhancement of voltage stability index (VSI) without incorporating the SSSC. The best, worst, average and the standard deviation values of the VSI that obtained by MSSA and SSA techniques are reported in Table. 2. The obtained VSI by application of MSSA and SSA are 0.1140 p.u. and 0.1166 p.u., respectively.



**FIGURE 7. Convergence performance of MSSA and SSA for voltage stability index (p.u) enhancement without inclusion the SSSC on IEEE30 bus-standard.**

In other words, the VSI is enhanced by 2.2298 % compared with SSA. Table 3 shows the values obtained by other algorithms, it is evidently that the obtained VSI by MSSA is better than HSA [34], SGA [34], PSO [34] PG-PSO [40], CMAES [39] and PSO-TVAC [40] by 4.2904 %, 5.6910 %, 4.6836 %, 8.2278 %, 16.9352 % and 22.6151 %, respectively. The optimal control values that assigned by MSSA and SSA are given in APPENDIX 3. Figure 7 shows the stable convergence characteristics of the proposed algorithm for the VSI.



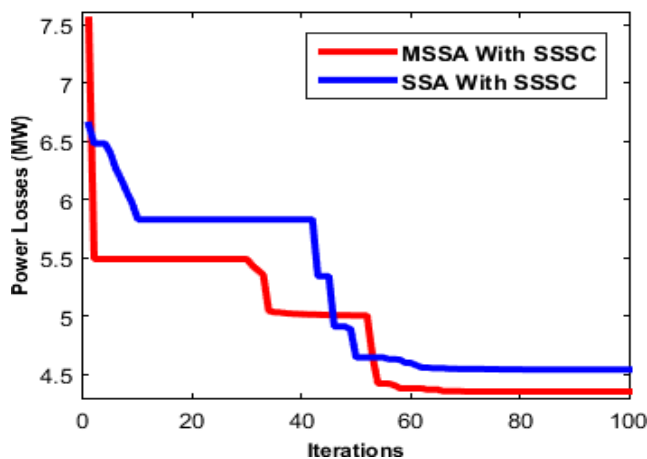
**TABLE 3. Results Comparison of Proposed MSSA to Different Optimization Techniques Without Inclusion of SSSC Using IEEE 30-Bus Standard.**

Algorithm	<i>Plosses (MW)</i>	<i>VD(p.u)</i>	<i>VSI(p.u)</i>	Algorithm	<i>Plosses (MW)</i>	<i>VD(p.u)</i>	<i>VSI(p.u)</i>
HSA [34]	4.7624	0.1349	0.1212	DE [36]	5.011	n/a	n/a
EP [33]	4.963	n/a	n/a	PG-PSO [40]	4.6425	0.1202	0.1264
SGA [34]	4.9408	0.1501	0.1230	FODPSO [37]	4.606	n/a	n/a
AGA [35]	4.926	n/a	n/a	FODPSO-EE [38]	4.5971	n/a	n/a
PSO [34]	4.9239	0.1424	0.1217	CMAES [39]	4.945	n/a	0.13965
CLPSO [35]	4.7208	n/a	n/a	PSO-TVAC [40]	4.8449	0.2064	0.1499

**B. CASE II: SOLVING THE ORPD WITH OPTIMAL INCLUSION THE SSSC ON IEEE30-BUS SYSTEM**

**1) MINIMAZATION OF POWER LOSSES**

In this case, the proposed MSSA and the conventional SSA are used to minimize the power losses with optimal inclusion the SSSC on IEEE 30-bus system. TABLE 2 shows the best, worst, mean and the standard deviation of the power losses. Judging from this table the best results are obtained by the proposed algorithm with optimal incorporating the SSSC compared with the conventional algorithm. The power loss is reduced to 4.3541 MW and 4.4361 MW by application the SSA and the MSSA or it is reduced by 5.1436 % and 3.3572 % compared to without incorporating the SSSC. Fig. 8 depicts the trends of the power losses using MSSA and SSA with optimal allocation the SSSC. It is obvious that the MSSA has stable convergence characteristics. The values of the control variables for this case are given in APPENDIX. 1. The optimal location of the SSSC is at 14<sup>th</sup> line while the optimal specified active and reactive power of the SSSC 39.63 MW and 17.09 MVar, respectively.



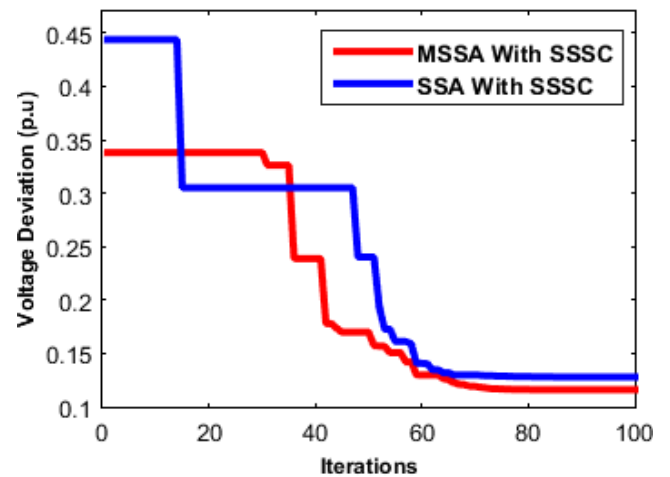
**FIGURE 8. Convergence performance of MSSA and SSA for power losses (MW) minimization with optimal inclusion the SSSC on IEEE30 bus-standard.**

**2) MINIMAZATION OF VOLTAGE DEVIATIONS**

In this case, the simulations are carried out by using both MSSA and SSA algorithms to minimize the voltage deviations (*VD*) with optimal inclusion the SSSC. The outcomes for this case are reported in Table 2 with its average, best,

worst and the standard deviations values with the simulation time. The minimum values of the *VD* that obtained by MSSA and SSA with optimal incorporating the SSSC are 0.1160 p.u. and 0.1279 p.u., respectively.

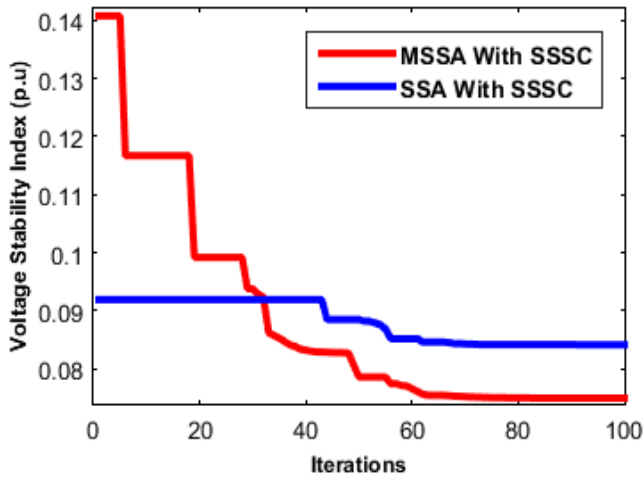
In other words, the voltage deviations are reduced with optimal incorporating the SSSC by 9.937% and 9.979% using MSSA and SSA respectively compared to without SSSC. The optimal values of the control variables as well as the optimal location and size of the SSSC by MSSA and SSA are listed in APPENDIX 2. The optimal location of the SSSC is at 29<sup>th</sup> line while the optimal specified active and reactive power of the SSSC –3.82 MW and 4.39 MVar, respectively. Fig. 9 verifies that the proposed algorithm has well convergence characteristics in terms of the *VD* minimization.



**FIGURE 9. Convergence performance of MSSA and SSA for Voltage deviation (p.u) minimization with optimal inclusion the SSSC on IEEE30 bus-standard.**

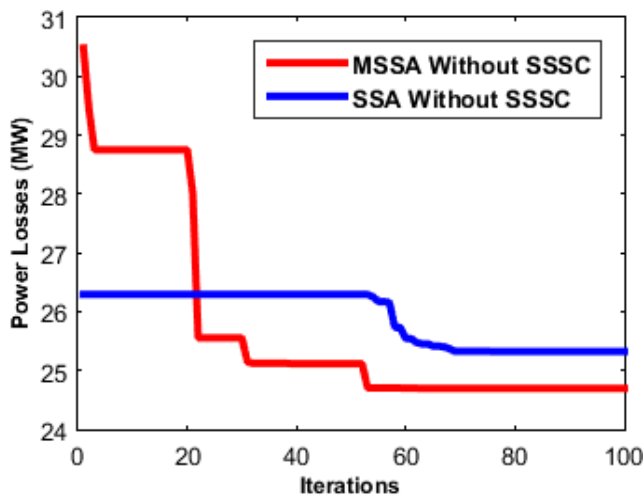
**3) ENHANCEMENT OF VOLTAGE STABILITY**

In this case, the objective function enhances the voltage stability index (*VSI*) by using MSSA and SSA techniques considering with optimal inclusion the SSSC in solving ORPD problem. Fig. 10 demonstrated the best convergence response getting by the proposed MSSA and the conventional SSA. The best, worst, average and the standard deviations values with the simulation time of MSSA and SSA techniques are reported in Table. 2. The best values are reported by the proposed MSSA technique to 0.0750 p.u.



**FIGURE 10.** Convergence performance of MSSA and SSA for voltage stability (p.u.) enhancement with optimal inclusion the SSSC on IEEE30 bus-standard.

which is 10.93% less than the conventional SSA considering with the optimal inclusion the SSSC. In addition, to enhance the VSI, the MSSA considering optimal inclusion the SSSC is reported 35.68% and 34.21% less compared to the case without optimal inclusion the SSSC by using SSA and MSSA techniques. The best values of the control variables for this case are reported in the APPENDIX. 3. The optimal location of the SSSC is at 36<sup>th</sup> line while the optimal specified active and reactive power of the SSSC 28.97 MW and 18.11 MVar, respectively.



**FIGURE 11.** Convergence performance of MSSA and SSA for power losses (MW) minimization without optimal inclusion the SSSC on IEEE57 bus-standard.

**C. CASE III: SOLVING THE ORPD WITHOUT INCLUSION THE SSSC ON IEEE 57BUS-SYSTEM**

**1) MINIMAZATION OF POWER LOSSES**

In this case, to solve the ORPD problem without optimal inclusion the SSSC controller to minimize the power losses by using MSSA and SSA techniques tested on IEEE 57-bus system. Fig. 11 illustrated the best convergence

response achieved by the proposed MSSA technique and conventional SSA for power loss reduction. The simulation outcomes reported by both techniques are given in Table. 4 including the average, the best, the worst and the standard deviation values with the simulation time. Judging from Table. 4, the minimum power losses obtained by MSSA is 24.6969 MW while the power losses obtained by conventional SSA technique is 25.3207 MW. The results indicated that the best reported values getting from the MSSA is 2.46% less than the conventional SSA. In addition, compared with the base case of 27.86 MW [45], the MSSA and the conventional SSA are reported to 11.35% and 9.11%, respectively. Judging from Table 4, the power losses that obtained by the proposed MSSA technique is also less than the reported than PSO [41], SGA [34], PSO-EE [38], CGA [33], FODPSO [37], L-SaDE [36], ICA [41], PSO-ICA [41], MOALO [9], and FODPSO [38] by 8.1063 %, 1.2453%, 4.3115%, 1.6443%, 5.0948%, 9.2952%, 6.2185%, 1.0369%, 4.0708%, and 4.2297%, respectively. The best values of the control variables for this case are reported in APPENDIX. 4. The Fig. 11, Table 4 and Table 5 indicated the efficient performance reported by the proposed MSSA technique to minimize the power losses without optimal inclusion of SSSC.

**2) MINIMAZATION OF VOLTAGE DEVIATIONS**

In this case, the ORPD problem is solved without inclusion the SSSC to minimize the voltage deviations (VD) by using MSSA and conventional SSA techniques on IEEE 57-bus system. Figure. 12 illustrated the best convergence performance achieved by the proposed MSSA over conventional SSA.

The outcomes computed by both optimization techniques are given in Table. 4 with their average, best, worst and the standard deviation values with the simulation time. According to the Table. 4, the best value of MSSA and conventional SSA are reported to 0.9402 p.u. and 0.9424 p.u., respectively. The results indicated that the proposed MSSA technique is reported 0.23% less than the conventional SSA.

In addition, Judging from the Table. 5, the proposed MSSA is also less than the other optimization techniques such as; PSO, ICA and hybrid PSO-ICA, respectively. The best control values for this case are given in APPENDIX. 5. The results towards the best performance achieved by the proposed MSSA technique are indicated from Fig. 12, Table. 4 and 5.

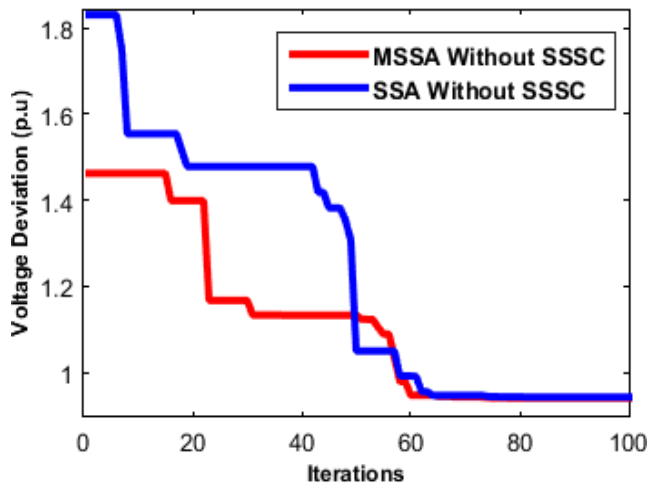
**3) ENHANCEMENT OF VOLTAGE STABILITY**

In this case, the ORPD problem is considered without optimal inclusion the SSSC controller to enhance the voltage stability index (VSI) by using the proposed MSSA and conventional SSA techniques applied on IEEE 57bus-system. The values of the parameter settings for the proposed MSSA technique are taken from Table. 1. The Figure. 13 illustrated the best convergence response getting from the proposed MSSA technique.

The simulation results for both techniques are given in Table. 4, with average, best, worst and the standard

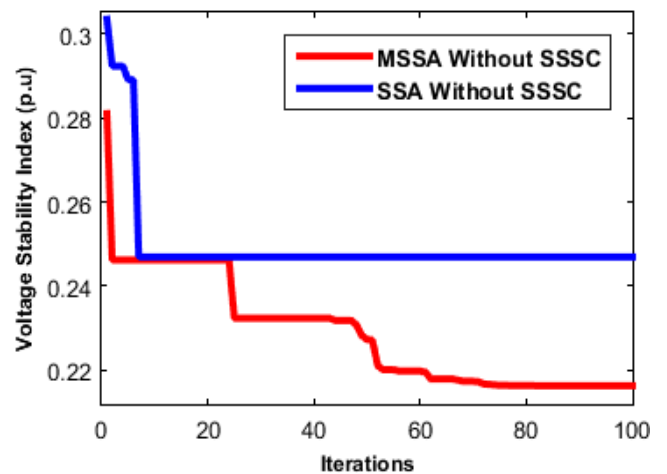
**TABLE 4.** Simulation Outcomes of MSSA and SSA Techniques With and Without Optimal Inclusion of SSSC Using IEEE 57-Bus Standard.

Power Losses (MW) With and Without SSSC for IEEE57 Bus Standard					
With SSSC					
Algorithm	Best	Average	Worst	Std	Time (sec)
SSA	24.1886	26.3989	29.0498	1.2104	26.4754s
MSSA (proposed)	23.9779	24.7942	26.3172	0.5601	49.5961s
Without SSSC					
Algorithm	Best	Average	Worst	Std	Time (sec)
SSA	25.3207	27.3543	30.1759	0.9355	9.3256s
MSSA (proposed)	24.6969	26.2678	29.9029	1.7488	19.1139s
Voltage Deviation with and Without SSSC for IEEE57 Bus Standard					
With SSSC					
Algorithm	Best	Average	Worst	Std	Time (sec)
SSA	0.9009	0.9867	1.0729	0.0445	43.8328s
MSSA (proposed)	0.8650	0.9586	1.1092	0.0532	56.4569s
Without SSSC					
Algorithm	Best	Average	Worst	Std	Time (sec)
SSA	0.9424	1.1290	1.2637	0.0795	7.9752s
MSSA (proposed)	0.9402	1.1031	1.2834	0.0823	19.4725s
Voltage Stability Index (p.u) With and Without SSSC for IEEE57 Bus Standard					
With SSSC					
Algorithm	Best	Average	Worst	Std	Time (sec)
SSA	0.2068	0.2403	0.2634	0.0149	62.3580s
MSSA (proposed)	0.1819	0.2293	0.2587	0.0201	105.2298s
Without SSSC					
Algorithm	Best	Average	Worst	Std	Time (sec)
SSA	0.2469	0.2648	0.2796	0.0085	9.3896s
MSSA (proposed)	0.2164	0.2285	0.2424	0.0074	19.0452s



**FIGURE 12.** Convergence performance of MSSA and SSA for voltage deviation (p.u) minimization without optimal inclusion the SSSC on IEEE57 bus-standard.

deviation values with the simulation time. Judging from the Table. 4, the best value for this case reported by MSSA and the conventional SSA are 0.2164 p.u. and 0.2469 p.u., respectively. The result indicated that the proposed MSSA is 12.35% less than the conventional SSA. Moreover, Judging from the Table. 5, the proposed MSSA is also less reported to the MOALO technique. The best values of the control variables for this case are given in APPENDIX. 6. The Fig. 13 and Table. 4 and Table. 5 endorsed the effectiveness of proposed MSSA.



**FIGURE 13.** Convergence performance of MSSA and SSA for voltage stability index (p.u) minimization without optimal inclusion the SSSC on IEEE57 bus-standard.

**D. CASE IV: SOLVING THE ORPD WITH OPTIMAL INCLUSION THE SSSC ON IEEE 57BUS-SYSTEM**

**1) MINIMAZATION OF POWER LOSSES**

In this case, the minimization of the power losses is achieved by the proposed MSSA and conventional SSA techniques considering the optimal inclusion of SSSC to ORPD problem applied on IEEE 57-bus system. Fig. 14, illustrated the best convergence performance obtained by the proposed MSSA technique over SSA. The simulation outcomes are given in Table. 4 for this case including the average, the best, the worst, the standard deviation values, and the simulation

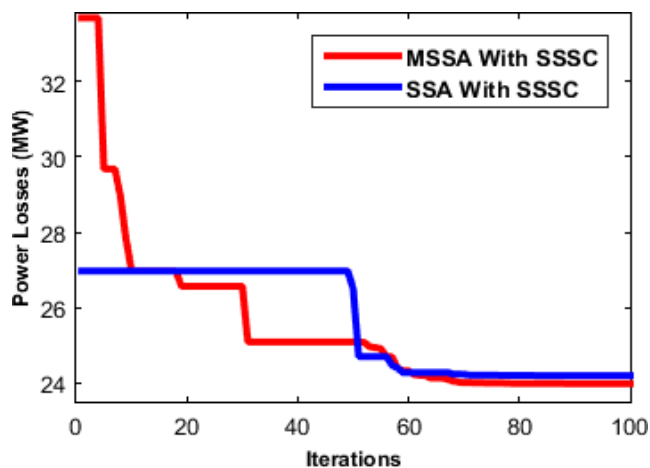
**TABLE 5. Results Comparison of Proposed MSSA to Different Optimization Techniques Without Inclusion of SSSC Using IEEE 57-Bus Standard.**

Algorithm	<i>Plosses</i> (MW)	<i>VD</i> (p.u)	<i>VSI</i> (p.u)	Algorithm	<i>Plosses</i> (MW)	<i>VD</i> (p.u)	<i>VSI</i> (p.u)
PSO [41]	27.55434	1.1379	n/a	L-SaDE [36]	27.9155	n/a	n/a
SGA [34]	25.64	n/a	n/a	ICA [41]	26.99968	1.2846	n/a
PSO-EE [38]	26.4616	n/a	n/a	PSO-ICA [41]	25.586	1.1548	n/a
CGA [33]	25.7440	n/a	n/a	MOALO [9]	26.3952	n/a	0.2854
FODPSO [37]	26.680	n/a	n/a	FODPSO-EE [38]	26.4390	n/a	n/a

time. Judging from the Table. 4, the best value for the power losses which are obtained by MSSA and conventional SSA are reported such as; 23.9779 MW and 24.1886 MW, respectively. In term of comparison, the proposed MSSA gives 0.87% reduction in power losses compare to the conventional SSA in case of optimal inclusion the SSSC to the ORPD problem.

Moreover, the power losses obtained by MSSA with optimal inclusion the SSSC are reduced by 2.911% and 5.30% compared to the case where MSSA and SSA are considered without inclusion the SSSC to the system.

The best values of the control variables for this case are given in APPENDIX. 4. The optimal location of the SSSC is at 18<sup>th</sup> line while the optimal specified active and reactive power of the SSSC are 36.29 MW and 10.33 MVar, respectively. It has also been observed that the consideration of the optimal inclusion of SSSC in ORPD gives the minimum the power losses while Fig. 14 and Table. 4 demonstrated towards the best performance achieved by the proposed MSSA techniques.



**FIGURE 14. Convergence performance of MSSA and SSA for voltage deviation minimization with optimal inclusion the SSSC on IEEE57 bus-standard.**

2) MINIMAZATION OF VOLTAGE DEVIATIONS

This case represents, the consideration of optimal inclusion the SSSC to the ORPD problem to minimize the voltage deviations (*VD*) by using the proposed MSSA and the conventional SSA algorithms applied on IEEE 57-bus system.

Fig. 15 demonstrated the efficient convergence response getting from the proposed MSSA algorithm to minimize the *VD*. The simulation results for this case are given in Table. 4, for MSSA and SSA techniques with their average, best, worst, the standard deviation values, and the simulation time. Judging from the Table. 4, the best values of the *VD* for this case by MSSA is 0.8650 p.u. and conventional SSA is 0.9009 p.u. The results indicated that the proposed MSSA is reported 3.98% less compare to SSA in case of with optimal inclusion the SSSC to ORPD.

Moreover, the proposed MSSA technique considering with optimal inclusion of SSSC, is also reported 7.99% and 8.21% less than the case of without optimal inclusion the SSSC to ORPD problem using MSSA and SSA techniques. The best values of the control variables for this case are reported in APPENDIX. 5. The optimal location of the SSSC is at 1<sup>th</sup> line while the optimal specified active and reactive power of the SSSC –16.71 MW and –32.34 MVar, respectively. It has been observed that solving the ORPD with optimal incorporating the SSSC can reduce the voltage deviations while Fig. 15 and Table. 4 demonstrated the better performance getting by the proposed MSSA technique for this case.

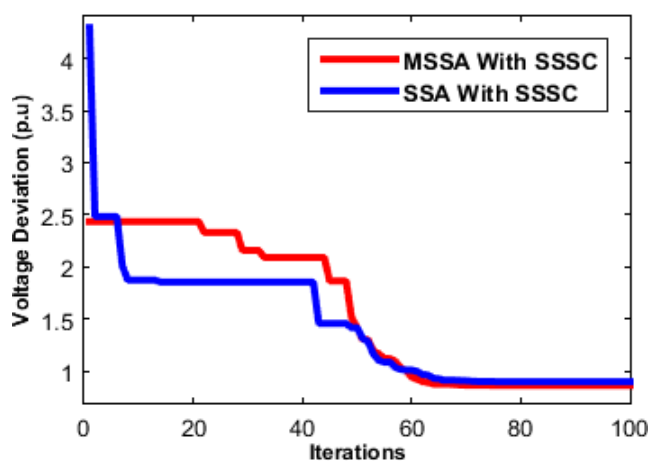
3) ENHANCEMENT OF VOLTAGE STABILITY

This case is considered with optimal inclusion of SSSC into the ORPD problem to enhance the voltage stability index (*VSI*) by applying the proposed MSSA and the conventional SSA techniques on IEEE 57-bus system. Fig. 16 illustrated the best convergence performance achieved by the proposed MSSA technique over the conventional SSA. The simulation results are given in Table. 4 for the MSSA and SSA algorithms with their average, best, worst and the standard deviation values with the simulation time. So, judging from the Table. 4, the best values of the *VSI* obtained by MSSA and SSA are 0.1819 p.u. and 0.2068 p.u., respectively.

The results indicated that the proposed MSSA technique is reported 12.04% less than the case of considering optimal inclusion the SSSC ORPD problem. In addition, judging from Table. 4, the MSSA techniques with optimal inclusion the SSSC outcomes are reported 15.94 % and 26.33% compared to the case without considering optimal inclusion the SSSC to ORPD problem. The values of the best control variables achieved for this case are given in APPENDIX. 6. The optimal location of the SSSC is at 1<sup>th</sup> line while the optimal specified active and reactive power of the SSSC are 18.26 MW and

**TABLE 6.** Control Variables of MSSA and SSA for Minimizing the Power Losses Using With and Without SSSC on IEEE 30-Bus Standard.

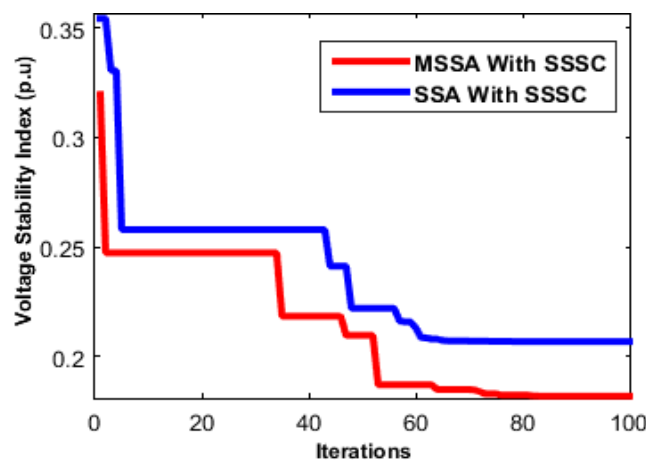
Control Variable	WITH SSSC		WITHOUT SSSC	
	Plosses (MW)		Plosses (MW)	
	SSA	MSSA (Proposed)	SSA	MSSA (Proposed)
VG 1	1.1	1.0999	1.1	1.1
VG 2	1.0945	1.0581	1.0548	1.0943
VG 5	1.0747	1.0797	1.0999	1.0969
VG 8	1.0889	1.0720	1.0817	1.0963
VG 11	1.0627	1.0068	1.0986	1.0999
VG 13	1.0284	1.0999	1.0873	1.0999
TC6-9	0.9615	1.0453	1.0739	0.9001
TC 6-10	1.0996	1.0167	1.0098	0.9024
TC 4-12	0.9553	1.0166	1.0588	0.9046
TC 27-28	0.9798	0.9741	1.0249	0.9018
QC 10	0.0381	0.0332	0.4887	0.4990
QC 12	0.01754	0.0283	0.4991	0.2987
QC 15	0.0264	0.0290	0.4902	0.4997
QC 17	0.0154	0.0228	0.4787	0.4379
QC 20	0.0441	0.0281	0.4248	0.4062
QC 21	0.0231	0.0315	0.4815	0.1433
QC 23	0.0226	0.0254	0.4738	0.4991
QC 24	0.0108	0.0286	0.4828	0.4997
QC 29	0.0382	0.0283	0.4883	0.1490
Psp	0.1694	0.3963	-	-
Qsp	0.4760	0.1709	-	-
Location	14	14	-	-
Vse	0.1900 [-0.503 <sup>o</sup>	0.1583 [-0.6251 <sup>o</sup>	-	-



**FIGURE 15.** Convergence performance of MSSA and SSA for voltage stability index (p.u) minimization with inclusion the SSSC on IEEE57 bus-standard.

15.56 MVar, respectively. The overall outcomes getting for this case, indicated that the consideration of the optimal inclusion the SSSC for ORPD gives the better response and help to improve the voltage stability (VSI). the proposed algorithm for this case which are given in Table. 4. The best outcomes the proposed algorithm for this case which are given in Table. 4 and Fig. 16 indicated the best response getting by the proposed MSSA to enhance the (VSI) considering optimal inclusion the SSSC.

It should be lighted here is that the proposed MSSA algorithm shows inferior results in early stages of iterations for some cases. This is due to its searching mechanism where in the earlier stages of iteration is that the populations (salps) updated their positions based on Levy distribution which enables the salps to jump to new areas for boosting



**FIGURE 16.** Convergence performance of MSSA and SSA for voltage stability index (p.u) minimization with inclusion the SSSC on IEEE57 bus-standard.

exploration process. Thus, a randomness process will be high in the earlier stages and it may lead to inferior results. While in the final stages, the populations will update their positions around the best solution in spiral path to boost the exploitation process. In sequent, the results in final stages of iterations are enhanced considerably.

**VI. OBTAINED RESULTS AND MAIN ACHIEVEMENTS**

The outcomes and achievement of the article can be summarized as follows:

- In application case of the MSSA for the IEEE 30-bus without SSSC, the power losses are reduced by 0.51%, the voltage deviations are reduced by 0.1553% and the voltage stability is enhanced by 2.2298% compared with application the SSA.



**TABLE 7. Control Variables of MSSA and SSA for Minimizing the Voltage Deviation Using With and Without SSSC on IEEE 30-Bus Standard.**

Control Variable	WITH SSSC		WITHOUT SSSC	
	VD (p.u)		VD (p.u)	
	SSA	MSSA (Proposed)	SSA	MSSA (Proposed)
VG 1	1.0003	1.0043	1.0162	0.9987
VG 2	0.9763	0.9539	0.9618	0.9698
VG 5	1.0721	1.0693	1.0293	1.0572
VG 8	0.9816	1.0039	1.0023	0.9820
VG 11	1.0727	1.0073	1.0811	1.0915
VG 13	1.0934	1.0254	1.0273	1.0599
TC6-9	1.0602	1.0148	1.0642	1.0592
TC 6-10	0.9261	0.9121	0.9139	0.9847
TC 4-12	1.0406	0.9925	0.9856	1.0318
TC 27-28	0.9597	0.9771	0.9614	0.9682
QC 10	0.0482	0.0399	0.3326	0.4763
QC 12	0.0494	0.0174	0.0582	0.4799
QC 15	0.0476	0.0318	0.1076	0.3782
QC 17	0.0296	0.0279	0.2251	0.4514
QC 20	0.0496	0.0334	0.4338	0.3786
QC 21	0.0084	0.0462	0.0420	0.3956
QC 23	0.0498	0.0390	0.4476	0.4425
QC 24	0.0012	0.0393	0.3184	0.4501
QC 29	0.0483	0.0456	0.2722	0.4839
Psp	0.9611	-0.0382	-	-
Qsp	-0.2477	0.0439	-	-
Location	1	29	-	-
Vse	0.1876 $\angle$ 1.7263°	0.0188 $\angle$ -0.9380°	-	-

**TABLE 8. Control Variables of MSSA and SSA for Minimizing the Voltage Stability Index Using With and Without SSSC on IEEE 30-Bus Standard.**

Control Variable	WITH SSSC		WITHOUT SSSC	
	VSI (p.u)		VSI (p.u)	
	SSA	MSSA (Proposed)	SSA	MSSA (Proposed)
VG 1	1.0483	1.0999	1.0998	1.0992
VG 2	0.9911	1.0999	1.0417	1.0695
VG 5	1.0302	1.0842	1.0998	1.0671
VG 8	1.0739	1.0999	1.0608	1.0995
VG 11	1.0459	1.0992	1.0993	1.0810
VG 13	1.0681	0.9999	1.0931	1.0504
TC6-9	0.9000	0.9018	1.0349	1.0337
TC 6-10	0.9021	0.9145	1.0511	0.9286
TC 4-12	0.9000	1.0347	1.0155	0.9979
TC 27-28	0.9352	0.9038	0.9357	0.9675
QC 10	0.0007	0.0492	0.1114	0.4387
QC 12	0.0385	0.0252	0.4379	0.4775
QC 15	0.0431	0.0484	0.4859	0.4827
QC 17	0.0179	0.0495	0.3075	0.4932
QC 20	0.0436	0.0499	0.0454	0.4841
QC 21	0.0383	0.0243	0.4544	0.4205
QC 23	0.0400	0.0495	0.3533	0.4722
QC 24	0.0411	0.0378	0.4560	0.4844
QC 29	0.0404	0.0382	0.4237	0.4963
Psp	0.4944	0.2897	-	-
Qsp	-0.1116	0.1811	-	-
Location	41	36	-	-
Vse	0.1735 $\angle$ 1.4612°	0.1542 $\angle$ 0.7657°	-	-

- In application case of the MSSA for the IEEE 30-bus with SSSC, the power losses are reduced by 3.3572%, the voltage deviations are reduced by 9.937% and the voltage stability is enhanced by 34.21% compared with solving ORPD without SSSC.
- In application case of the MSSA for the IEEE 57-bus without SSSC, the power losses are reduced by 2.46%, the voltage deviations are reduced by 0.23% and the voltage stability is enhanced by 12.35% compared with application the SSA.
- In application case of the MSSA for the IEEE 57-bus with SSSC, the power losses are reduced by 2.911%, the voltage deviations are reduced by 7.99% and the voltage stability is enhanced by 15.94 % compared with solving the ORPD solution without SSSC.

**TABLE 9. Control Variables of MSSA and SSA for Minimizing the Power Losses Using With and Without SSSC on IEEE 57-Bus Standard.**

Control Variable	WITH SSSC		WITHOUT SSSC	
	<i>Plosses (MW)</i>		<i>Plosses (MW)</i>	
	SSA	MSSA (Proposed)	SSA	MSSA (Proposed)
VGT-1	1.0978	1.1	1.0735	1.0999
VGT-2	1.0605	1.0896	1.0619	1.0935
VGT-3	1.0868	1.0988	1.0418	1.0701
VGT-6	1.0278	1.0647	1.0219	1.0716
VGT-8	1.0862	1.0987	1.0466	1.0930
VGT-9	1.0135	1.0819	1.0389	1.0685
VGT-12	1.0595	1.0881	1.0285	1.0692
Tc4-18	0.9017	0.9389	0.9507	1.0936
Tc4-18	0.9079	1.0591	0.9000	1.0726
Tc21-20	0.9067	1.0568	1.0059	1.0699
Tc24-26	0.9079	1.0008	0.9850	0.9397
Tc7-29	0.9000	0.9951	0.9001	1.0693
Tc34-32	0.9793	1.0502	0.9650	1.0702
Tc11-41	0.9008	1.0644	0.9000	0.9762
Tc15-45	0.9332	1.0433	0.9403	1.0725
Tc14-46	0.9150	1.0132	0.9099	1.0250
Tc10-51	0.9297	1.0790	0.9388	1.0736
Tc13-49	0.9002	1.0079	0.9042	1.0148
Tc11-43	0.9159	1.0157	0.9595	1.0933
Tc40-56	0.9508	1.0349	0.9397	1.0091
Tc39-57	0.9345	0.9751	0.9050	1.0698
Tc9-55	0.9522	1.0236	1.04017	1.0322
QC18	0.1805	0.1378	0.1194	0.1328
QC25	0.1268	0.1372	0.0012	0.1968
QC53	0.0357	0.1533	0.0464	0.0363
Psp	-0.2260	0.3629	-	-
Qsp	0.0949	0.1033	-	-
Location	25	18	-	-
Vse	0.1326 / -1.6464°	0.1728 / 1.1336°	-	-

**TABLE 10. Control Variables of SSA and MSSA for Minimizing the Voltage Deviation Using With and Without SSSC on IEEE 57-Bus Standard.**

Control Variable	WITH SSSC		WITHOUT SSSC	
	<i>VD (p.u)</i>		<i>VD (p.u)</i>	
	SSA	MSSA (Proposed)	SSA	MSSA (Proposed)
VGT-1	1.0151	1.0312	1.0133	1.0179
VGT-2	0.9540	1.0447	1.0437	0.9500
VGT-3	1.0433	1.0563	1.0055	1.0009
VGT-6	1.0621	0.9852	1.0014	1.0261
VGT-8	1.0284	1.0869	0.9504	0.9631
VGT-9	1.0723	1.0219	1.0143	1.0237
VGT-12	1.0047	1.0239	1.0070	1.0069
Tc4-18	0.9598	0.9037	0.9682	0.9051
Tc4-18	0.9779	1.0175	0.9054	1.0331
Tc21-20	0.9915	1.0137	1.0229	0.9789
Tc24-26	1.0714	1.0679	1.0822	1.0251
Tc7-29	0.9504	0.9213	0.9000	0.9209
Tc34-32	0.9026	0.9021	0.9002	0.9001
Tc11-41	0.9032	0.9003	0.9047	0.9007
Tc15-45	0.9114	0.9086	0.9026	0.9877
Tc14-46	0.9064	1.0091	0.9739	0.9025
Tc10-51	0.9961	1.0299	0.9602	0.9450
Tc13-49	0.9053	0.9001	0.9001	0.9203
Tc11-43	0.9702	0.9987	0.9751	0.9195
Tc40-56	0.9154	1.0077	0.9154	0.9769
Tc39-57	1.0242	0.9086	0.9746	1.0329
Tc9-55	0.9885	1.0278	0.9764	0.9933
QC18	0.0227	0.0946	0.0189	0.0049
QC25	0.0003	0.1918	0.0035	0.0699
QC53	0.0003	0.1532	0.0708	0.1903
Psp	-0.3201	-0.1671	-	-
Qsp	-0.3477	-0.3234	-	-
Location	1	1	-	-
Vse	0.1166 / -3.0192°	0.1604 / 2.4601°	-	-

**VII. CONCLUSION**

This article presented MSSA for solving ORPD problem with optimal allocation of the SSSC controller. The exploration

and exploitation processes of the conventional salp swarm algorithm (SSA) is enhanced by updating the positions of the salps using the Levy flight distribution (LFD) and a spiral

**TABLE 11. Control Variables of MSSA and SSA for Minimizing the Voltage Stability Index Using With and Without SSSC on IEEE 57-Bus Standard.**

Control Variable	WITH SSSC		WITHOUT SSSC	
	VSI (p.u)		VSI (p.u)	
	SSA	MSSA (Proposed)	SSA	MSSA (Proposed)
VGT-1	1.0999	1.0663	0.9500	1.0987
VGT-2	1.0013	1.0729	0.9500	1.0939
VGT-3	1.0742	1.0995	1.1000	1.1000
VGT-6	0.9932	1.0978	0.9500	1.0978
VGT-8	1.0971	1.0989	0.9500	1.0956
VGT-9	1.0697	1.0509	1.1000	1.1000
VGT-12	1.0999	1.0716	1.1000	1.0841
Tc4-18	0.9969	0.9815	0.9000	1.0860
Tc4-18	0.9408	1.0452	0.9000	0.9104
Tc21-20	1.0193	0.9493	0.9000	0.9795
Tc24-26	1.0835	1.0712	1.1000	1.0958
Tc7-29	0.9362	1.0942	0.9000	0.9012
Tc34-32	0.9028	1.0118	0.9000	0.9004
Tc11-41	0.9002	1.0431	0.9000	0.9876
Tc15-45	0.9191	1.0053	0.9000	0.9021
Tc14-46	0.9016	1.0765	0.9000	0.9093
Tc10-51	0.9542	0.9015	0.9000	0.9033
Tc13-49	0.9060	0.9517	0.9000	0.9043
Tc11-43	0.9097	0.9339	0.9000	0.9791
Tc40-56	1.0151	1.0996	0.9000	1.0859
Tc39-57	0.9775	1.0978	0.9000	1.0916
Tc9-55	0.9465	1.1	0.9000	0.9823
QC18	0.1757	0.1913	0.0000	0.1872
QC25	0.1885	0.1942	0.0293	0.1983
QC53	0.1809	0.1779	0.0078	0.1974
Psp	-0.2826	0.1826	-	-
Qsp	-0.1117	0.1556	-	-
Location	39	1	-	-
Vse	0.2000 $\angle -2.3423^\circ$	0.1670 $\angle -2.1154^\circ$	-	-

movement of the salps around the best solution. The aim of incorporating the SSSC controller with ORPD in the power system is to reduce the power losses and voltage deviations as well as enhance voltage stability. A simplified power injection model is utilized to represent the SSSC. Consequently, the modifications in Jacobian matrix are avoided. The proposed algorithm was tested on standard IEEE 30-bus and IEEE 57-bus test systems. The yielded results were compared with those computed with some other algorithms to verify its effectiveness. The obtained results demonstrated that the superiority of the proposed algorithm for solving the ORPD.

**APPENDIX 1**  
See Table 6.

**APPENDIX 2**  
See Table 7.

**APPENDIX 3**  
See Table 8.

**APPENDIX 4**  
See Table 9.

**APPENDIX 5**  
See Table 10.

**APPENDIX 6**  
See Table 11.

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