International Journal on Electrical Engineering and Informatics - Volume 12, Number 3, September 2020

Multi-Objective Optimal Reactive Power Dispatch using Levy Interior Search Algorithm

Karthik Nagarajan[1], Ayalur Krishnamoorthy Parvathy[2], and Arul Rajagopalan[3]

[1,2]Department of Electrical & Electronics Engg., Hindustan Institute of Technology & Science, Chennai, Tamilnadu, India, [3]School of Electrical Engg., Vellore Institute of Technology Chennai Campus, Chennai, Tamilnadu, India
nkarthik@hindustanuniv.ac.in

Abstract: In planning and operation processes of power systems, the most critical and outstanding problem is the optimal scheduling of reactive power resources. The current research study considered real power loss as well as the deviation of voltage magnitude as objective functions since these two play important roles in a power system's operations and control. Due to the above-mentioned considerations, bi-objective optimization takes a form here. In the recent times, lot of meta-heuristic optimization techniques was implemented to elucidate ORPD problem. One such recently advanced algorithm named Interior Search Algorithm is utilized to find a solution for challenges in power system. It is observed that it is not producing accurate solution and convergence characteristic curve is also not smooth. In order to enhance the searching ability of ISA a new method called Levy Interior Search Algorithm (LISA) was proposed in this paper. In this two different strategies of LISA were proposed. In order to validate the proposed algorithm, LISA is implemented on five various standard test systems comprising IEEE 30-bus, IEEE 57-bus, IEEE 118-bus, IEEE 300-bus and IEEE 354-bus test systems. To conclude, application results of LISA are compared with the results of other optimization techniques reported in literature. The comparison reveals that the LISA Strategy-II outperformed all other optimization techniques in terms of robustness, accuracy and convergence speed.

Keywords: Optimal Reactive Power Dispatch (ORPD), Real Power loss, Voltage Deviation Index (VDI), Interior Search Algorithm (ISA), Levy Interior Search Algorithm (LISA).

1. Introduction

In Optimal Power Flow (OPF) problem, a significant and critical sub-problem is optimal reactive power dispatch since it enacts a vital role in augmenting the protection as well as economy in a power system. [1]. The reactive power flow and maintenance of voltage profile in today's power systems got changed into a bottleneck predicament in which a minuscule-level carelessness also can put at risk of the system security [2]-[3]. To alleviate the disadvantage of ORPD, the power system's reactive power needs to be reallocated to the phase of minimization of real power loss and voltage profile deviation. Since ORPD is considered as a severe non-convex and multi-challenging non-linear problem, the solution for such a problem eventually attempts to segregate the finest setting of all control variables where the selected objective functions are minimized. In design variables, both continuous variable (such as generator bus voltage) as well as discrete variables (such as tap setting of transformers and shunt reactive power sources) are present [4]. In spite of the fact that the reactive power generation is not inclusive of fuel cost, it still has an impact on the whole power system cost. So, it becomes mandatory to oversee the reactive power resources using ORPD in the power system [5].

Owing to the reduction in transmission line loss will lead to the minimization of total generation cost and as a result increase in the societal benefit. Since the deviation of bus voltage is not tolerable to any further extent, it is crucial to preserve the bus voltage magnitude in today's digital era. Another important point is that all devices are designed for precise range of voltage in power systems, and any deviation in the voltage magnitude will cause the damage of equipment. Consequently it is essential to maintain all voltages in an adequate range. Due to this,

Received: April 20th, 2020. Accepted: September 8th, 2020
DOI: 10.15676/ijeei.2020.12.3.8

the researcher considered the minimization of Voltage Deviation Index (VDI) and minimization of real power loss (P_{loss}) as the objective functions of ORPD problem [6, 7].

The ORPD problem has a primary objective i.e., to mitigate the losses incurred in transmission line and maintain the precise limits of voltage profiles. Several computation techniques for instance the linear programming [8–10], modified interior point method [11], quadratic programming [12], Newton method [13] have been applied to elucidate the ORPD problem. All these numerical optimization approaches cannot assure to attain a holistic optimal solution for these challenges because of its non-convexity attribute. Moreover, these optimization approaches have a number of constraints like derivability and continuity of the fitness function. In the past decades, a lot of population based optimization approaches are employed to elucidate non-linear and non-convex constrained optimization problems [14, 15]. Even though earlier optimization methods are competent to afford ORPD elucidation to a definite scope, however there is prospect for bringing advance development in the optimization approaches employed. In [16], a hybrid genetic algorithm was proposed to reveal the ORPD problem so as to mitigate the losses incurred in transmission line. Three different test systems have considered validating the hybrid GA-IPM algorithm. In [17]-[19], ORPD problem was addressed using Differential Evolution (DE) algorithm for reducing the transmission line losses and enhancement of voltage magnitude of buses.

M. Basu [20] proposed Quasi-Oppositional DE (QODE) algorithm to address the ORPD problem by taking voltage stability, voltage deviation and losses in transmission line as objective functions. In [21], Rudra Pratap Singh et. al.,[21] applied Particle Swarm Optimization (PSO) on three different test systems to find a solution for ORPD problem. The researchers developed the ORPD problem as a single objective optimization problem in which they separately minimized the transmission line loss as well as the voltage deviation. Mehdi Mehdinejad et. al., proposed a hybrid optimization algorithm on the basis of PSO and Imperialist Competitive Algorithm (ICA) to mitigate the loss incurred in transmission line and deviation of voltage [22]. In the literature [23], an enhanced Pseudo-gradient Search PSO algorithm was proposed to overcome the challenges faced in ORPD problem [23]. This research article considered deviation in voltage, voltage stability index as well as the loss in transmission line as its objective functions. TLBO (Teaching-Learning Based Optimization) algorithm was proposed in the study [24] to elucidate the ORPD problem. Quasi-oppositional TLBO is implemented to attain the optimal real power losses [25]. Lagrangian decomposition approach was implemented with the intention of solving the ORPD problem [26]. Harmony Search Algorithm (HSA) was formulated in correlation music enhancement process in which a group of music players cobble the pitches of their instruments simultaneously so to achieve the best harmony. The move to elucidate the non-convex ELD problem was successful when using Harmony Search Algorithm (HSA) [27] whereas in another study [28] Improved Harmony Search (IHS) algorithm was incorporated to tackle the ELD problem. In the study [29], HSA algorithm was made use of, to overcome the OPF problem in which the study considered three diverse objective functions. According to the study [30], the OPF problem was attempted to be overcome by applying IHS algorithm. In the study [31], a new and a modified HAS algorithm was proposed by K. Valipour et al as a solution to overcome ORPD problem. The researchers [32], when trying to reveal the problem, leveraged a variety of optimization approaches such as ECHT (Ensemble of Constraint Handling Technique), Self-adaptive Penalty (SP), ε-Constraint (EC), Stochastic Ranking (SR), and Feasible Solutions (FS).

The researchers incorporated a modified version of SFLA (Shuffled Frog Leaping Algorithm) to overcome the ORPD problem. This paper observed the incorporation of Nelder-Mead(NM) algorithm with SFLA algorithm in order to add exploitation characteristic to SFLA. A. A. Abou El-Ela et.al, implemented ant colony optimization (ACO) technique for elucidating the ORPD problem [34]. In this paper, ACO algorithm is validated on three different test systems including practical West Delta Network system. Artificial Bee Colony (ABC) algorithm was proposed in the literature [35] to mitigate the real power loss in both IEEE 30-bus as well as IEEE 118-bus systems. In order to overcome the ORPD problem, the researchers P.K. Roy et al proposed the Biogeography Based Optimization (BBO) technique [36]. According to the literature [37-38], ORPD problem can be overcome by Gravitational Search Algorithm which can be utilized to reduce the deviations of total voltage and loss of active power. GSA was enhanced and proposed as a new method by B. Shaw et al to overcome the ORPD problem [39]. Based on the leadership qualities and the hunting behavior of grey wolves, M. H. Sulaiman et al proposed a Grey Wolf Optimizer (GWO) method in order to tackle the ORPD problem [40]. The ELD problem was handled by chaotic firefly algorithm, a modified firefly algorithm in the study [41]. Nelder-Mead (NM) optimization algorithm and Hybrid Firefly Algorithm (HFA) have been implemented in [42] for elucidating the ORPD problem. In [43], Hybridized Tabu Search-Simulated Annealing (HTSSA) algorithm is used to find a solution for ORPD problem. In the study [44], an Exchange Market Algorithm was proposed by the researcher in order to mitigate the deviating voltage of power system and reduce the real power losses in addition to enhancement of the voltage stability index. A Chaotic Krill Herd Algorithm (CKHA) was proposed by the researchers Aparajita Mukherjee et al to find a solution for ORPD problem [45]. In [46], Whale optimization algorithm (WOA) is implemented to elucidate the ORPD problem. In [46], WOA was implemented on IEEE 14-bus as well as 30-bus and a practical Algerian 114-bus system. Rebecca Ng Shin Meia et. al., proposed Moth-Flame Optimization (MFO) algorithm for addressing the ORPD problem [47]. In [48], the researchers proposed a DSA (Differential Search Algorithm) to minimize the transmission line loss, enhance the voltage profile and the voltage stability.

Gandomi [49] proposed a type of art-inspired optimization technique named interior search algorithm (ISA). ISA is based on interior design and decoration to determine the global optimum solution. In [50], ISA is implemented to address the multi-objective economic emission dispatch problem. In [51], economic load dispatch problem is elucidated using ISA algorithm for a microgrid test system. In the case of conventional ISA, new variables are generated using rand functions [49]. So this leads to local optima. With the purpose of enhancing the search capability of ISA, Levy flight is integrated with ISA to generate better optimal solution. System identification using LISA based approach encompasses faster convergence and does not entail derivative information since it utilizes a stochastic random search using the concepts of Levy flight. The incorporation of Levy flight approach enhances the local search avoiding local trapping of the optimal solution. An appropriate tuning of control parameter α has been carried out with the intention of attaining equilibrium between intensification and diversification phases. The main contributions of this paper are summarized as follows:

- Incorporation of Levy Flights with conventional ISA to exploit the search space
- Two different strategies of Levy Interior Search Algorithm were implemented
- A novel multi-objective algorithm based on the ISA technique for solving the optimal reactive power dispatch problem (ORPD) in large-scale power system is proposed.
- The proposed algorithm was successfully tested on standard IEEE 30-bus, IEEE 57-bus and IEEE 118-bus test systems and on large-scale IEEE 300-bus system and IEEE 354-bus system.

In conventional ISA, r_3 is a random variable which varies from 0 to 1 which is related with mirror work and the α is fixed as 0.2 for all iterations. Here α is a threshold parameter which is used to distribute the elements into two groups, composition group and mirror group. In Levy ISA, α is varied with respect to the number of iterations which enhances the ability of local search of the proposed algorithm. In other words, α is varied dynamically during the iterations from smaller value to a larger value with respect to the number of iterations.

In LISA Strategy-I, the value of parameter r_3 is fixed as 0.3 and the value of α is varied dynamically with respect to the no. of iterations. By assigning a fixed value of the parameter r_3, better optimum solution is obtained.

In LISA Strategy-II, both the values of α and r_3 are varied dynamically which yields better accuracy and convergence speed and also leads to the local search capability of the proposed algorithm.

Comparison results reveal that application of LISA Strategy-II provides lower voltage deviation and lower real power loss.

2. Problem Formulation

In this study, the researcher formulated the multi-objective ORPD problem to be a real one through the mitigation of real power loss and voltage deviation magnitude simultaneously meeting the expectations of equality and inequality challenges.

Generally, the mathematical model of the ORPD problem can be represented as follows:

$$Min\ f = Minimize\{f_1, f_2\} \tag{1}$$

$$\text{Subject to:} \begin{cases} g(x,u) = 0, & Equality\ Constraints \\ h(x,u) \leq 0, & Inequality\ Constraints \\ u_j^{lower} \leq u \leq u_j^{upper} & Variable\ limits \end{cases} \tag{2}$$

Where $f_1, and\ f_2$ are the objective functions, x represents the vector of dependent variables and u represents the vector of control variables. They are represented as follows:

$$x^T = [V_L \dots\dots\dots V_{NLB}, Q_{G1} \dots\dots\dots Q_{G,NG}, S_1 \dots\dots\dots S_{NTL}] \tag{3}$$

$$u^T = [V_{G1} \dots\dots\dots V_{GNG}, T_1 \dots\dots\dots T_{NT}, Q_{C1} \dots\dots\dots Q_{CNC}] \tag{4}$$

A. Mitigation of Real Power Loss

With the increasing rate of energy consumption, the amount of power losses increased too, making the reduction of power losses as an important aim for system operators [32,33]. Then, the transmission line loss can be determined as

$$f_1 = P_{loss} = \sum_{n=1}^{NL} g_n \left[V_j^2 + V_k^2 - 2V_jV_k \cos(\delta_j - \delta_k)\right] \tag{5}$$

where g_n denotes the conductance of n[th] line which conjoins bus j and bus k whereas the number of transmission lines is denoted by NL.

B. Minimization of Voltage Deviation Index

Maintenance of proper voltage level at load buses is taken as the second objective for the ORP problem to ensure the security of the power system. Due to the deviation from the magnitude of the nominal voltage the life and efficiency of the electrical equipment gets reduced. Thus the minimization of the deviation of the magnitude of the voltage at the load buses is essential for the optimization of voltage profile at load buses.

$$f_2 = \sum_{k=1}^{NL} \left|V_k - V_k^{ref}\right| \tag{6}$$

The number of load buses is denoted by NL whereas the V_k^{ref} denotes the pre-assumed reference value for the magnitude of the voltage at kth load bus. V_k^{ref} is typically fixed as 1.0 pu.

C. Equality and inequality constraints

One must consider the losses occur in transmission lines in order to accomplish appropriate economic load dispatch. When using the Newton-Raphson and B-coefficients approach, it is easy to find out the transmission line losses. By using Newton-Raphson, the researcher obtained the optimal power flow solution which is utilized to make decision on real power loss P_{loss}. One can exhibit the active power loss subjected under equality constraints as follows.

$$P_{gj} - P_{Dj} - V_j \sum_{j=1}^{NB} V_k \left[G_{jk} \cos(\delta_j - \delta_k) + B_{jk} sin(\delta_j - \delta_k)\right] = 0 \tag{7}$$

$$Q_{gj} - Q_{Dj} - V_j \sum_{j=1}^{NB} V_k \left[G_{jk} \sin(\delta_j - \delta_k) + B_{jk} cos(\delta_j - \delta_k)\right] = 0 \tag{8}$$

where j=1,2,...NB; NB denotes the total number of buses whereas the magnitudes of bus j and bus k are represented by V_j and V_k respectively; Q_{gj} denotes the reactive power output at j[th] bus; the voltage angles of bus j and k are represented by δ_j and δ_k. ; B_{jk} and G_{jk} denote the transfer susceptance and conductance between the buses, j and k. The bus active and reactive power loads are denoted by P_{Dj} and Q_{Dj} respectively.

Each generating unit's original power generation output should be kept under control i.e., it should have minimum and maximum boundaries

$$P_{gimin} \leq P_{gi} \leq P_{gimax} \tag{9}$$

P_{gi} denotes the real power output of i[th] generating unit whereas the maximum and minimum real power output are denoted as P_{gimax} , P_{gimin} for the i[th] generating unit.

$$Q_{gimin} \leq Q_{gi} \leq Q_{gimax} \tag{10}$$

$$V_{gimin} \leq V_{gi} \leq V_{gimax} \tag{11}$$

Equation (8) is related with tap changer of transformers which are used with the intention of regulating the magnitude of the voltage. Equation (9) is associated with the result of all switch-controllable shunt parts, for example, capacitor banks. As a final point, (10) & (11) are security limitations comprising loading of transmission lines constraints and magnitude of the load voltage.

$$T_r^{min} \leq T_r \leq T_r^{max} \tag{12}$$

$$Q_{C_s}^{min} \leq Q_{C_s} \leq Q_{C_s}^{max} \tag{13}$$

$$V_{L_k}^{min} \leq V_{L_k} \leq L_{L_k}^{max} \tag{14}$$

$$|S_{l_t}| \leq S_{l_t}^{max} \tag{15}$$

D. Multi objective optimal reactive power dispatch (MO-ORPD)

There are several methods available to elucidate the multi-objective optimization problem. Some of the methods are weighted sum approach [59], evolutionary algorithms [60] and e-constraint method [61]. In this paper, the proposed multi-objective optimal reactive power dispatch problem is elucidated using the weighted sum approach. In this weighted sum approach, different weights are utilized for the contradictory objective functions to create various set of Pareto optimal solutions and then the various weights chooses the best compromise solution from a set of Pareto optimal solutions.

The problem is solved using the weighted sum approach as follows:

$$\min[J(x,u) = w_1 f_{1,pu}(x,u) + w_2 f_{2,pu}(x,u) \tag{16}$$

where $w_1 + w_2 = 1$

The above-mentioned multi-objective ORPD problem can be articulated mathematically as a nonlinear constrained optimization problem, which can be expressed as:

$$x^T = [[V_L]^T, [Q_G]^T, [S_L]^T]$$

$$U^T = [[V_G]^T, [Q_C]^T, [T]^T] \tag{17}$$

3. Fuzzy logic based assortment of finest compromise solution

In the meantime the objective functions (1) and (2) are not in the similar dimension and range, a fuzzy logic satisfying approach is proposed to determine the standardized form of the objective functions in (12). Each objective function is mapped it to the interval [0, 1] by employing the fuzzy logic approach. When taking a decision, it is important to choose the best compromise solution from the available optimal solutions. In order to identify the best compromise solution, the study used the fuzzy membership approach [27]. The r[th] objective function f_r of individual k is characterized by a membership function μ_r^k due to indefinite feature of the decision maker's conclusion which is defined as

$$f_{r,pu}^{(k)} = \begin{cases} 1 & f_r \leq f_r^{min} \\ \frac{f_r^{(k)} - f_r^{max}}{f_r^{min} - f_r^{max}} & f_r^{min} < f_r < f_r^{max} \\ 0 & f_r \geq f_r^{max} \end{cases} \tag{18}$$

The f_r^{max} and f_r^{min} denote the maximum and minimum values of r[th] fitness function amongst the available non-dominated solutions whereas the normalized membership function μ^k is calculated similarly for every non-dominated result k as

$$\mu^k = \frac{\sum_{j=1}^{N} \mu_j^k}{\sum_{k=1}^{r} \sum_{j=1}^{N} \mu_j^k} \tag{19}$$

In the above equation, r denotes the total countable non-dominated solutions. The finest compromise solution comprises maximum value of μ^k.

For the complete set of Pareto optimal solutions, the number of best compromise solution (BCS) is attained by applying min–max criterion [62] as follows:

$$\max(min_j(f_{r,pu})) \tag{20}$$

This indicates that the solution which has the largest value of $min_j(f_{r,pu})$, is the best compromise solution. In this paper for objective functions (1) and (2), the normalized fitness values are expressed as[63]:

$$P_{L,pu} = f_{1,pu} = \frac{P_L - P_L^{max}}{P_L^{min} - P_L^{max}} \tag{21}$$

$$VD_{pu} = f_{2,pu} = \frac{VD - VD^{max}}{VD^{min} - VD^{max}} \tag{22}$$

4. Levy Interior Search Algorithm

Being an aesthetic optimization technique, ISA replicates the attractive approaches used for interior embellishing and designing a particular space [48]. ISA encompasses two essential features to carry out the determination of solution in search space. In order to improve the optimization capability of ISA, Levy Interior Search Algorithm is developed by integrating the principle followed in Levy flights which are nothing but a flight pattern that can be observed in birds. This proposed algorithm is called as Levy Interior Search Algorithm (LISA).

Advantages of proposed LISA algorithm:

(i) Composition Phase to address exploration

The objective of this feature is to determine an appropriate composition for components that creates an attractive background that assures customer's requirements. In the composition phase, composition of elements is modified in order to attain the better aesthetic view.

(ii) Mirror work to address exploitation

With the intention of creating an attractive decoration mirror work is modeled. In this phase, a mirror is positioned in the vicinity of the global best to ascertain a pertinent outlook.

The foremost objective of using LISA is to devise a design problem in that way fulfilling all constraints.

The implementation steps of LISA algorithm is summarized as:

Step 1: Characterize the search space and indiscriminately generate a population of elements x_k for k = 1, 2, 3... n between lower boundaries (LB) and upper boundaries (UB).

Step 2: The objective f_k is determined for complete elements among which the finest fitness element is showcased as the global best and denoted as x_{gb} .

Step 3: The other elements are segregated in an uneven format into dual groups on the basis of the probability of α, composition phase and mirror work. If the value of r_3 is less than α, the element goes into the mirror group or else it falls into the composition group. In this, the r_3 denotes a random number which is present between 0 and 1.

In a conventional ISA α has been considered as a predetermined value [48]. It has been understood that with huge number of elements during composition phase, one can improve the capability of global search. With an aim to enhance the convergence speed, the current study employed a dynamic α that differed linearly up to 80% of the iterations, but after that, it is retained as constant close to 1. When the α is retained as near to 1 at later stages of the iterations, a larger mirror group may evolve that can aid in local search. So, the variable α results in faster convergence.

Step 4: In the composition phase, vary each element indiscriminately enclosed by the narrow search space.

$$x_j^k = LB^k + (UB^k - LB^k)r_2 \tag{23}$$

Where x_j^k corresponds to j[th] solution in k[th] run and r_2 is an arbitrary value between 0 and 1.
Step 5: In the mirror phase, a mirror is placed extensively flanked by every element and the finest element. The location of the mirror can be determined as:

$$x_{m,j}^k = r_3 x_j^{k-1} + (1 - r_3)x_{gb}^k \qquad (24)$$

Where r_3 is an indiscriminate value ranging from 0 to 1. The modified location of the image can be devised as:

$$x_i^k = 2x_{m,i}^k - x_i^{k-1} \qquad (25)$$

Step 6: The position of the global finest component is to some extent altered by employing Levy flight approach. This Levy flight method is utilized for exploration process which is associated with confined search.

$$x_{gb}^j = x_{gb}^{j-1} + \delta \otimes \mathrm{Levy}(\lambda) \qquad (26)$$

where δ is referred as a scale factor which is assigned in proportion to dimension of the exploration space. Here δ is fixed as 1.

$$\mathrm{Levy}(\lambda) = 0.01\ \mathrm{X} \frac{r_5 \sigma}{|r_6|^{\frac{1}{\beta}}} \qquad (27)$$

Where σ is determined as:

$$\sigma = [\Gamma(1+\lambda) * \sin(\pi * \tfrac{\lambda}{2})/(\Gamma\left(\tfrac{1+\lambda}{2}\right) * \lambda * 2^{\frac{(\lambda-1)}{2}})]^{1/\lambda} \qquad (28)$$

where $\Gamma(x) = (x-1)!$, r_5, r_6 are random numbers in the range of [0,1] and $1 < \beta \leq 2$, where β has a constant value of 1.5 in this study[64].

Levy(λ) characterizes the step length which is incorporated by the Levy distribution with infinite values of variance and mean with $1<\lambda<3$. λ is the distribution factor and $\Gamma(.)$ represents the gamma distribution function.
Step 7: Determine the values of fitness of modified locations of the element and images. Retain the global best element if the value of the fitness at the updated location is superior to at the previous location.
Step 8: Recur steps 2 to 7 till the maximum number of iterations is attained.

5. Results and Discussions

In order to substantiate the capability of ISA in elucidating the ORPD problem, ISA is implemented to five various standard test systems comprising of IEEE 14-bus, IEEE 30-bus, IEEE 57-bus, IEEE 118-bus, IEEE 300-bus and IEEE 354-bus test systems. MATLAB software was used to execute the simulation process. As per the study [56], the control variables and active power losses for the initial conditions for IEEE 30-bus, 57-bus and 300-bus system were taken for the study.

A. Test system 1 (IEEE 30-bus test system)

At first, a small-scale power system is only considered. There are 6 generation units, 4 transformers, 41 transmission lines and 9 shunt compensators present in a standard test system. Based on the study [57], the control variables' minimum and maximum boundaries are finalized with 2.834 p.u being the load demand at 100 MVA base. The lower and upper limits for magnitude of the bus voltage are 0.94 p.u. and 1.06 p.u., respectively for the PQ bus. The dimension of control variables is 19, which comprise 6 generator voltages including the slack bus voltage. Figure 2 reveal the attained simulation results attained using LISA, ISA and other optimization techniques for the optimization of real power loss and VDI. The optimum Pareto front of the proposed LISA Strategy-II algorithm evidently offer a lower front and well-distributed over the trade-off front compared to the fronts of LISA Strategy-I and ISA as illustrated in Figure 2. The minimum value of power loss obtained using the proposed LISA Strategy-II was 4.4928 MW by assigning the weighting factor 'w' as 1.By assigning 'w' as 0 the minimum value of voltage deviation attained was 0.1482 for the proposed LISA Strategy-II. Figure 1 denotes the convergence features of real power loss in the determination of ORPD problem on IEEE 30-bust test system using ISA, LISA strategy-I and LISA strategy-II respectively. The convergence characteristic reveals that LISA strategy-II reaches the optimal value of real power loss at the end of 13th iteration. In addition, the computation time of LISA strategy-II is lesser compared to other optimization algorithms. The convergence characteristic curve with reference to minimization of power loss of the proposed LISA Strategy-II seems to be smooth and rapid in comparison with ISA and LISA Strategy-II as shown in Figure 1.By varying the value of weighting factor 'w' and by the application of fuzzy logic, the best compromise solution value obtained using the proposed LISA Strategy-II was 4.8193 MW and 0.374 respectively [57]. Furthermore, Figure 2 denotes the allocation of the achieved real power losses and VDI with the help of ISA, LISA strategy-I and LISA strategy-II on IEEE 30-bus test system for 50 independent runs. Figures 2, 4 and 5 reveal that the obtained results are too nearer to global optimum solution. Consequently, LISA strategy-II is robust and stable owing to the lesser values of active power loss and VDI.

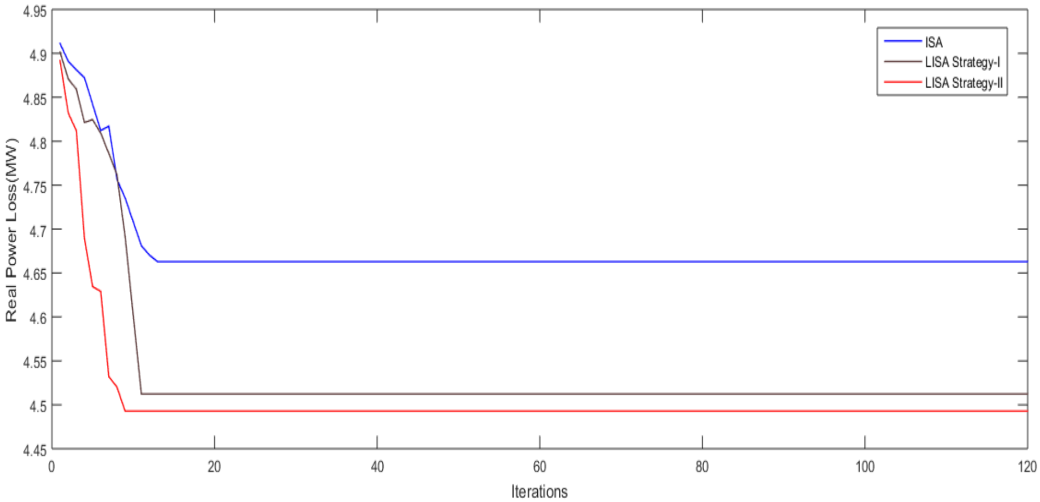

Figure 1. Cost Convergence characteristic for IEEE 30-bus system

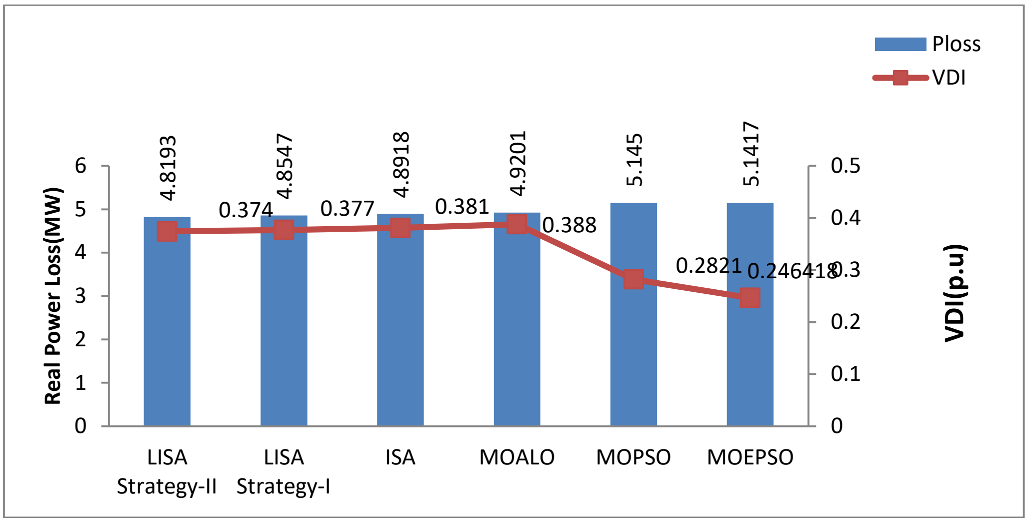

Figure 2. Comparison of simulation results for the minimization of real power loss and voltage deviation for IEEE 30-bus system

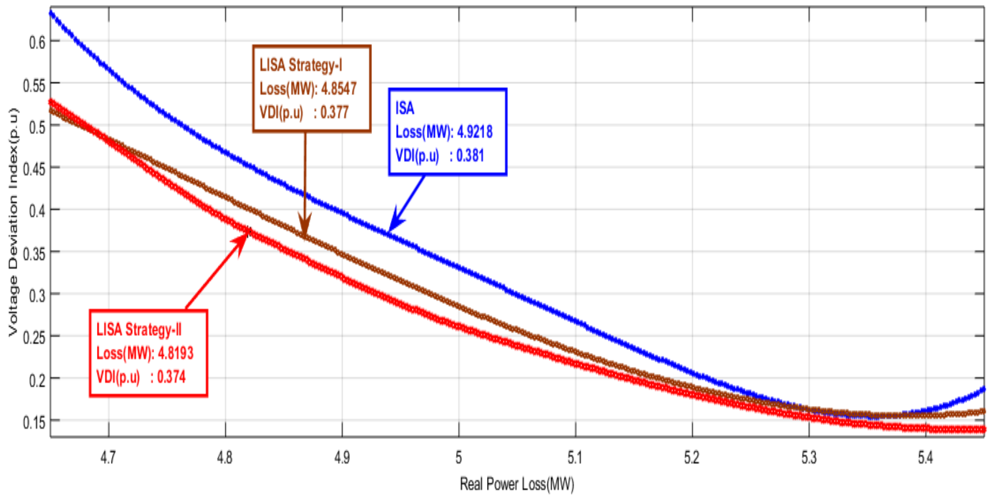

Figure 3. Best-obtained Pareto-fronts for IEEE 30-bus system

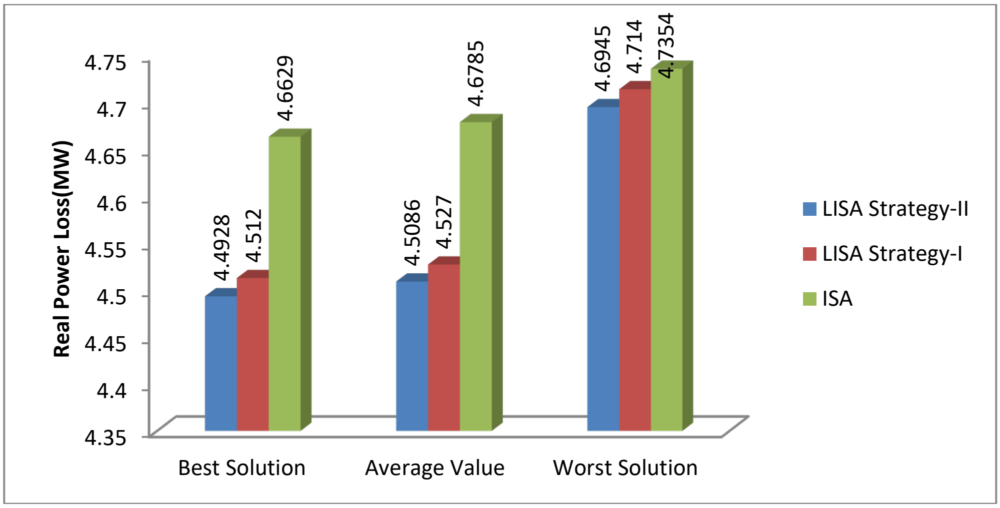

Figure 4. Statistical results obtained using ISA and LISA for IEEE 30-bus system for the minimization of real power loss

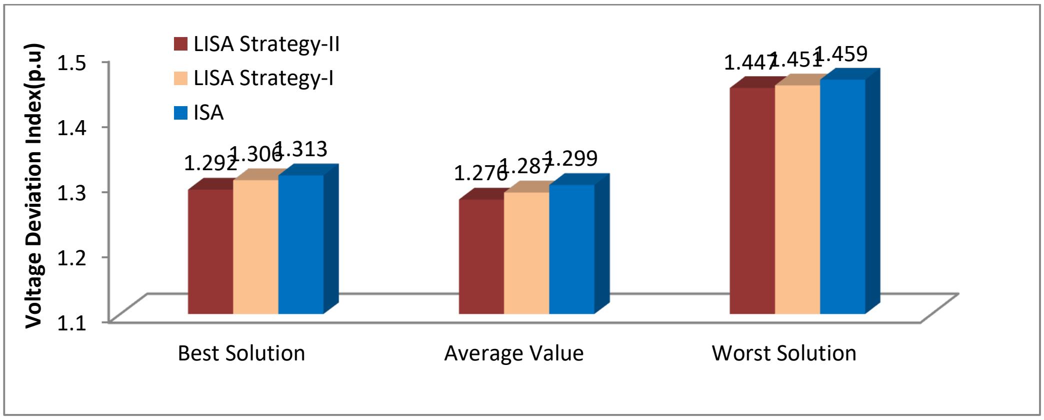

Figure 5. Statistical results obtained using ISA and LISA for IEEE 30-bus system for the minimization of VDI

B. Test system 2 (IEEE 57-bus test system)

There are 7 generating units present in the standard IEEE 57-bus test system at 1, 2, 3, 6, 8, 9, and 12 buses [53]. The 57-bus network [58] comprises 17 transformers, 80 branches and 3 capacitor banks in buses 8, 25 and 53. The lower and upper voltage limits were 0.94 and 1.06 pu set for all the busses including slack bus. The power demand considered in this 57-bus network is (12.508+ j3.364) p.u. In order to overcome the ORPD problem, the study incorporated the LISA algorithm whereas the study results achieved were contrasted and analyzed with the results achieved when applying MOALO[56], MOPSO, MOEPSO and ISA optimization techniques. Simulation was carried out for 50 independent test runs using ISA, LISA strategy-I and LISA strategy-II. Furthermore, application results attained using LISA is compared with ISA, MOALO [56], MOPSO and MOEPSO algorithms under the same constraints. From this comparison, it can be perceived that LISA strategy-II provides better efficiency than LISA strategy-I, ISA, MOALO [56], MOPSO and MOEPSO in terms of computation time and superiority of solution [57]. By assigning the weighting factor as 1, minimization of real power loss is performed. Figure 9 represents the convergence characteristics obtained for the minimization of active power loss using ISA, LISA strategy-I and LISA strategy-II respectively. From the Figure 9, it is concluded that the proposed LISA Strategy-II provides steady and quick convergence characteristic. The minimum value of voltage deviation is attained by substituting the value of the weighting factor 'w' as 0. Figure 10 portrays the trade-off characteristics between real power loss and VDI attained by using ISA, LISA strategy-I and LISA strategy-II respectively. Furthermore, from Figure 10, it can be observed that the Pareto optimal front has a good distribution of the non-dominated solutions, thus corroborating the efficacy of the proposed LISA Strategy-II to elucidate the nonlinear multi-objective optimization problem. The solution obtained by the proposed LISA Strategy-II method was better than LISA strategy-I, ISA, MOALO [56], MOPSO [57] and MOEPSO [57] algorithms and is presented in Figure 6. The weighting factor w value is reduced from 1 to 0 in steps of 0.001 and for each the value of w one compromise solution is generated. The real power loss value will increase and the magnitude of voltage deviation at the load buses will reduce in each step concurrently if the value of the weighting factor w is reduced. Lastly, the fuzzy logic approach described in Section 3 is utilized to decide the best compromise solution (BCS) from a set of compromise solutions. Figures 7 and 8 presents the statistical results obtained using the proposed LISA Strategy-II and other meta-heuristic optimization techniques. Thus, arriving at a conclusion, the proposed LISA algorithm employing strategy-II revealed a very modest performance with respect to the LISA strategy-I, ISA and MOALO[56]. Moreover, the computational time for LISA employing strategy-II was less than when compared to LISA Strategy-I and ISA. Application results abundantly substantiate the ability of LISA Strategy-II to tackling the challenges of equality and inequality that occur in ORPD problem.

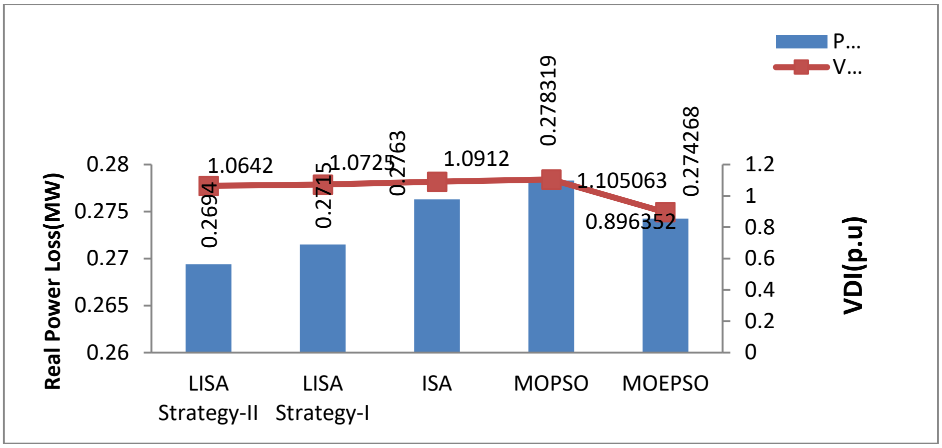

Figure 6. Comparison of simulation results for the minimization of real power loss and voltage deviation for IEEE 57-bus system

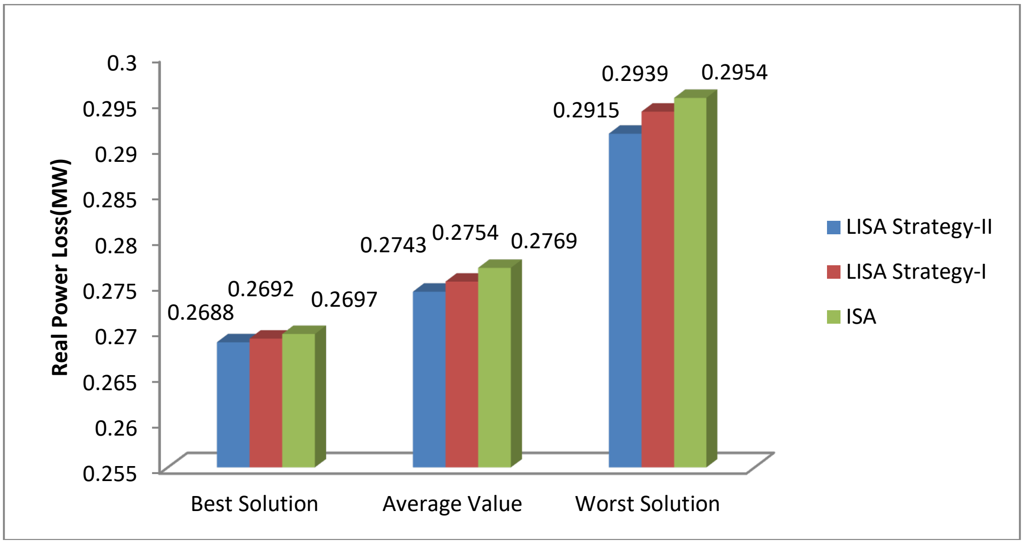

Figure 7. Statistical results obtained using ISA and LISA for IEEE 57-bus system for the minimization of real power loss

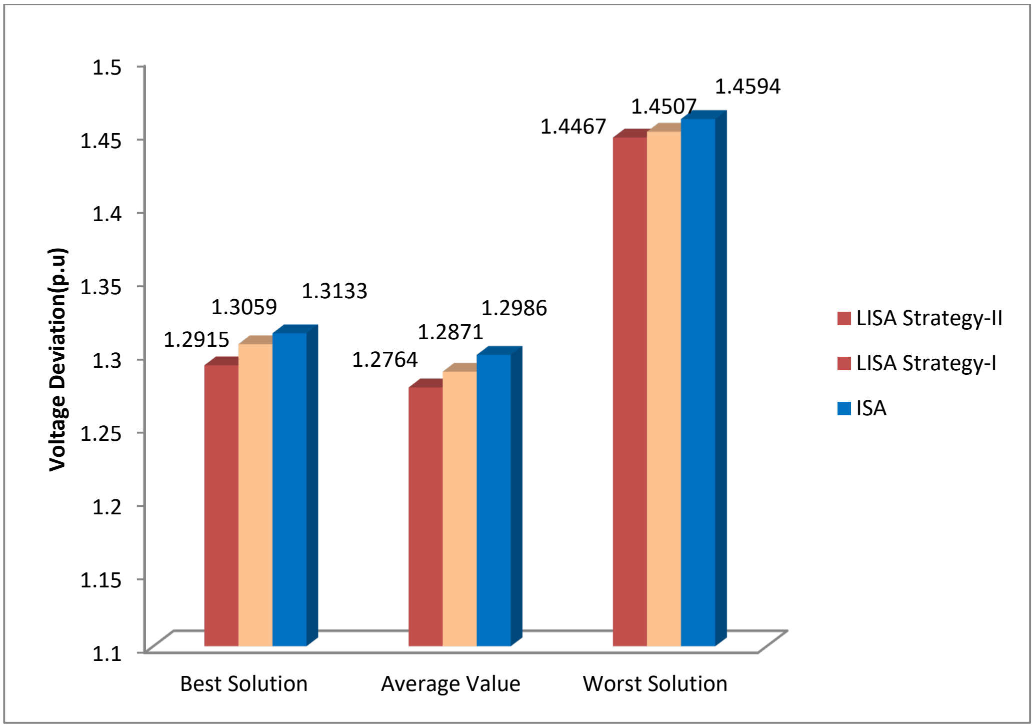

Figure 8. Statistical results obtained using ISA and LISA for IEEE 57-bus system for the minimization of VDI

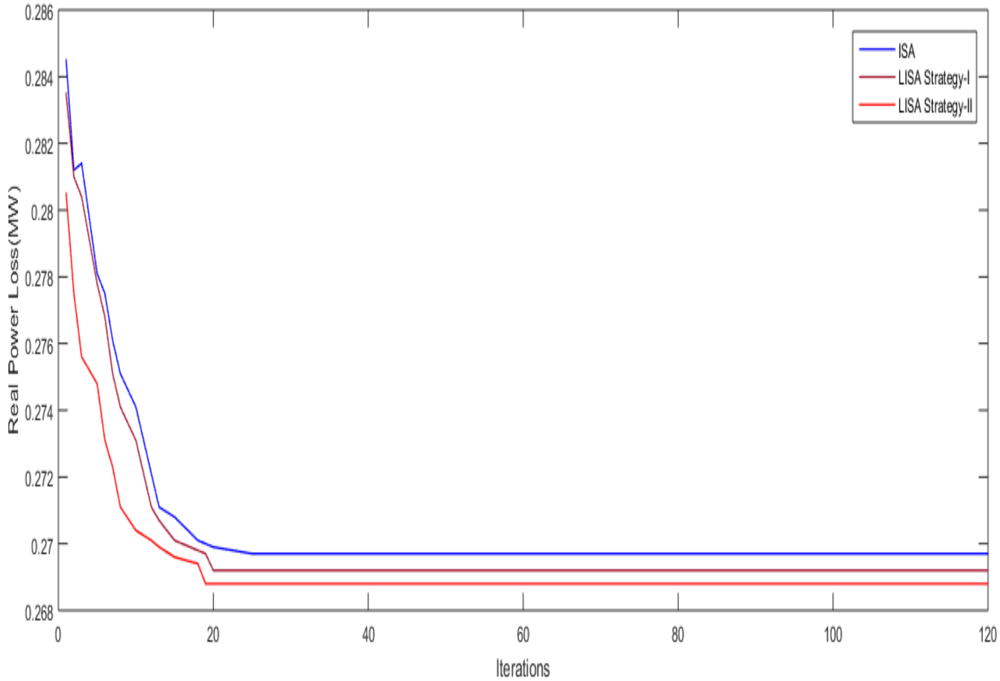

Figure 9. Convergence characteristic for IEEE 57-bus system

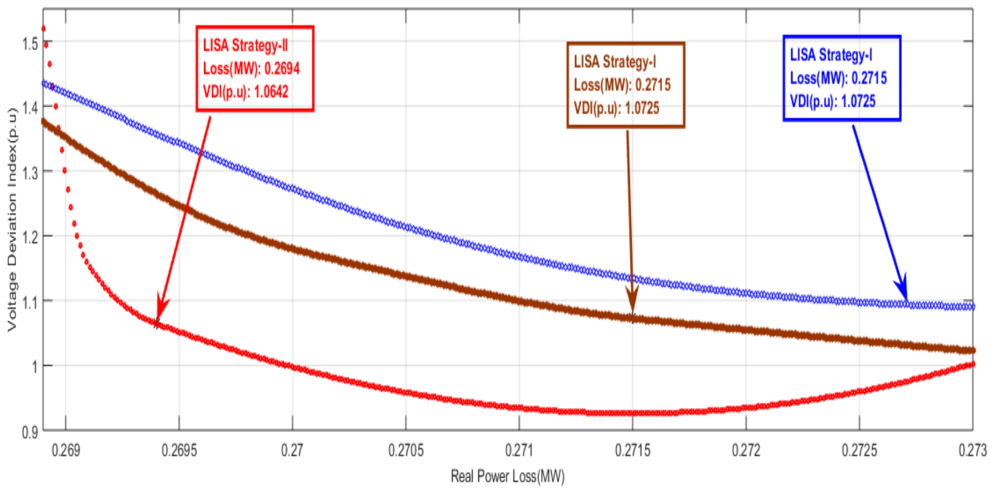

Figure 10. Best-obtained Pareto-fronts for IEEE 57-bus system

C. Test system 3 (IEEE 118-bus test system)

The next test system considered is IEEE 118-bus test system which is a medium-scale power system to validate the efficacy of LISA employing strategy-II in elucidating the ORPD problem. This test system comprises 54 generating units, 9 transformers, 186 transmission lines and 14 reactive power resources [55]. As per study [58], the researcher considered the minimum and maximum boundaries. From the study [58], the test system's bus data and line data were taken. The minimum value of active power loss of 119.79 MW for the proposed LISA Strategy-II was attained by substituting the weighting factor 'w' as 1. As per Figure 14, the optimal real power loss value attained when using the proposed LISA Strategy-II is better when compared with other optimization algorithms [21]. Figures 14 and 15 reveals the statistical comparison of application results for the minimization of real power loss for the proposed LISA Strategy-II and other optimization algorithms [26]. The mean value of real power loss is very close to the mean value which substantiates effectiveness of the proposed LISA Strategy-II in generating global optimum solution [43]. By assigning the weighting factor 'w' as 0, the minimization of the magnitude of bus voltages was performed. In Figure 15, the optimal value of the voltage deviation index attained by the proposed LISA Strategy-II and other optimization algorithms is presented [21]. The weighting factor w is reduced in steps of 0.001 from the value of 1 to 0 to generate a set of compromise solutions. The best compromise solution is attained from a set of compromise solution by employing the method of fuzzy logic. Simulation results for the minimization of both real power losses and VDI are presented in Figure 13. A comparison of the results achieved from LISA and other such optimization algorithms is presented in the Figure 13. Such algorithms also were proposed for the minimization of real power loss [26]. Alternatively, the simulation results attained by LISA employing strategy-II were compared with the results from other meta-heuristic optimization techniques to minimize VDI. Figure 13 illustrates the optimal results attained by LISA strategy-I, LISA strategy-II, ISA and other optimization approaches so as to minimize both real power loss and VDI [23]. It is observed from Figure.13 that LISA employing strategy-II outperforms other optimization techniques. Further, the highest, average as well as the least solutions to minimize the active power transmission losses in 50 independent runs using LISA strategy-II were 119.79 MW, 131.69 MW and 121.49 MW respectively. Correspondingly, when minimizing the VDI with the help of LISA strategy-II, the values were 0.2819 pu, 0.2924 pu, 0.3294 pu respectively. Furthermore, convergence for obtaining real power loss and VDI is achieved in 55, 54 and 53 iterations respectively for ISA, LISA strategy-I and LISA strategy-II. Execution time for LISA strategy-II is lesser compared to other optimization algorithms similar to previous test system. The convergence characteristic for this standard test system is presented in Figure.11. The convergence characteristic curve of the proposed LISA Strategy-II is fast and smooth in attaining the optimal solution. Figure 12 represents the trade-off characteristics between real power loss and VDI for ISA, LISA strategy-I and LISA strategy-II with the intention of revealing the efficiency of LISA in elucidating large-scale optimization problems [32]. Consequently, the optimum pareto front of the proposed LISA Strategy-II algorithm afford a lower front and well-distributed over the trade-off front compared to the pareto fronts of LISA Strategy-I and ISA. Also the locations of best compromise solutions of LISA Strategy-II, LISA Strategy-I and ISA are represented in Figure 12. Moreover, simulation results substantiate the efficacy of LISA to elucidate the ORPD problem in comprehensive test systems.

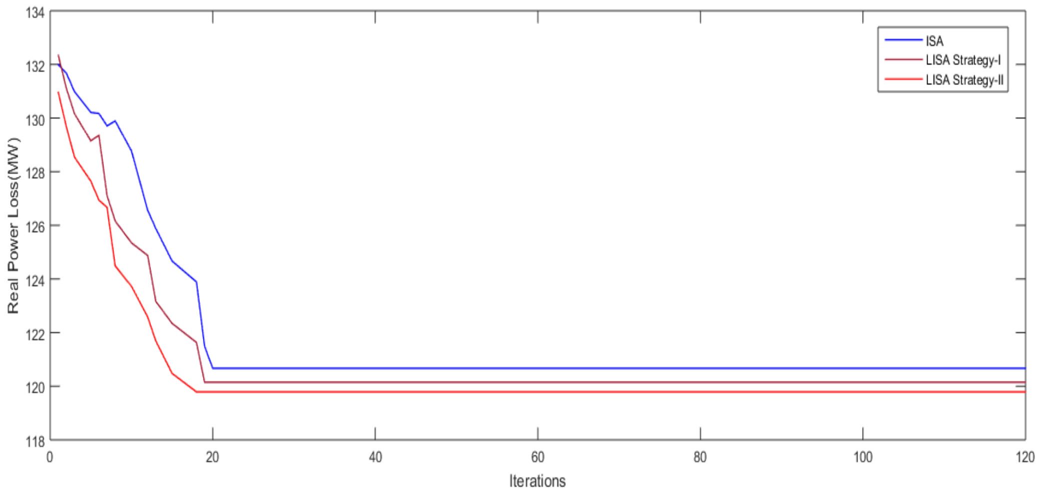

Figure 11. Convergence characteristic for IEEE 118-bus system

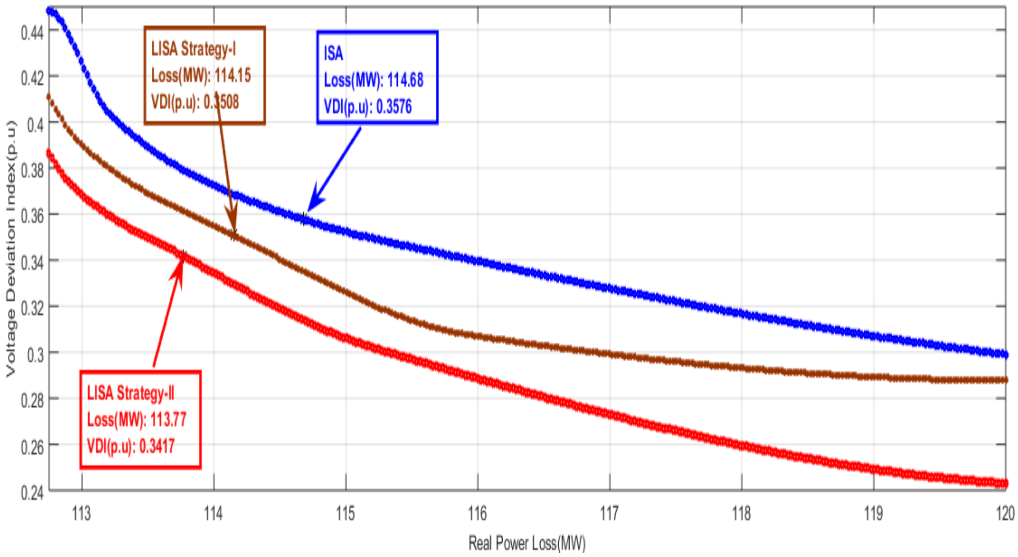

Figure 12. Best-obtained Pareto-fronts for IEEE 118-bus system

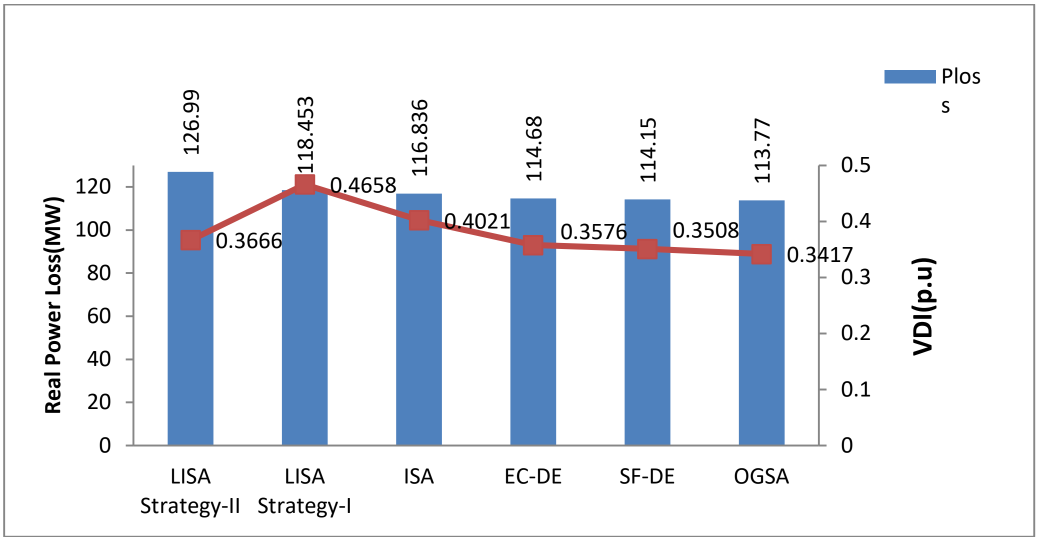

Figure 13. Comparison of simulation results for the minimization of real power loss and voltage deviation for IEEE 300-bus system

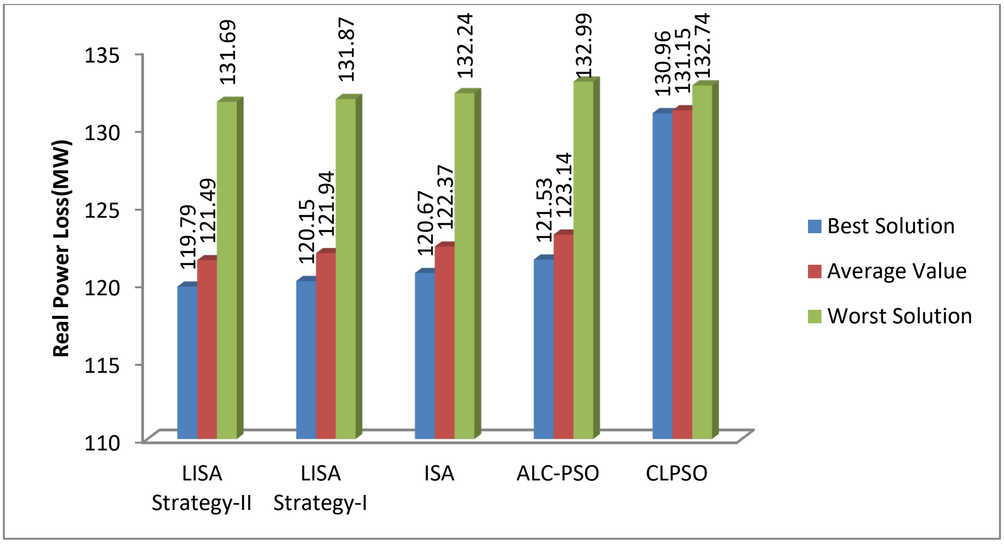

Figure 14. Statistical comparison of real power loss minimization results of IEEE 118-bus test power system based on 100 trial runs.

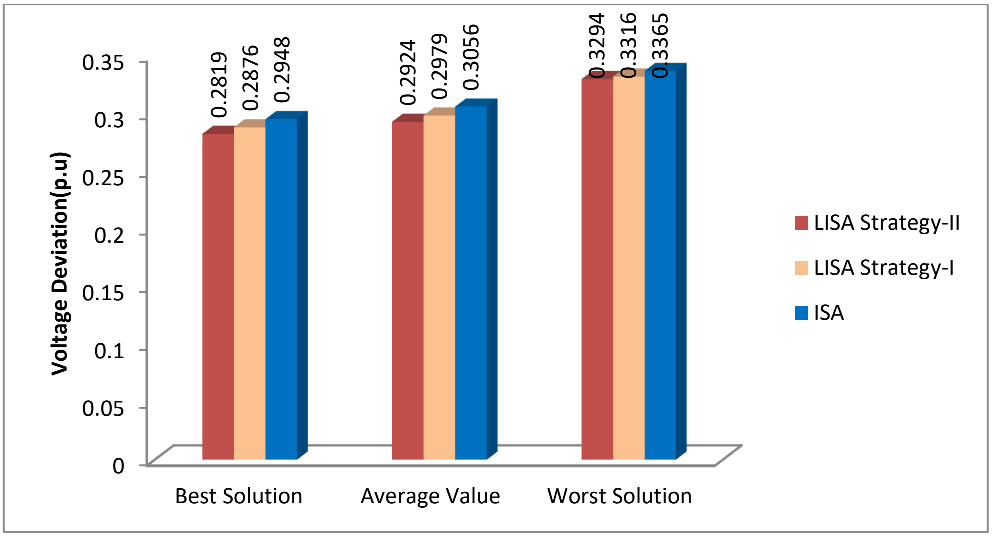

Figure 15. Statistical results for the minimization of VDI obtained using ISA and LISA for IEEE 118-bus system

D. Test system 4 (IEEE 300-bus test system)

The IEEE 300-bus was made use of, as a test system in order to examine the capability of LISA in overcoming the ORPD problem in a large-scale power system [58]. In this test system, there were 411 transmission lines in which 107 branches were with off-nominal tap ratios, a total of 69 generating units in addition to 14 parallel compensators were also present as per the study [56] guidelines. The total power demand considered was (235.258 + j77.8797) p.u. The minimum and maximum value of control variables were considered according to the study [56]. The minimum value of active power loss is attained by substituting the value of weighting factor ‘w’ as 1. The convergence characteristics for the real power loss attained using ISA, LISA strategy-I and LISA strategy-II is portrayed in Figure.16. It is observed from the Figure.16, the proposed LISA Strategy-II algorithm has rapid and steady convergence characteristic to determine the optimal solution. The minimization of the voltage magnitude at load buses is carried out by assigning the weighting factor as 0. The best compromise solution is obtained from a set of pareto optimal solutions by the application fuzzy logic approach. Figure 18 reveals the best solution obtained for both VDI as well as the real power loss. In Figures 19 and 20, the statistical comparison of simulation results for the proposed LISA Strategy-II and other algorithms considered are tabulated for the minimization of real power loss and VDI respectively. Further, the highest, average and the least solutions to minimize the losses of active power transmission during 50 standalone runs when utilizing LISA strategy-II were 391.7016 MW, 392.4658 MW and 395.4548 MW respectively. Accordingly, in the minimization of VDI utilizing LISA, these values were 8.2418 pu, 8.3915 pu, 8.5014 pu respectively. It is important to record that the magnitudes of voltages of all load buses are well within the boundaries set. Figure 17 showcase the distribution of non-dominant solutions which exactly denote the pareto optimal front with the help of ISA, LISA strategy-I and LISA strategy-II. It can be concluded that the proposed LISA Strategy-II algorithm is more appropriate to elucidate the multi-objective ORPD problem than the other optimization techniques. Furthermore, the proposed LISA Strategy-II algorithm provides good distributions of the non-dominated solutions and also guarantees the feasibility of solutions obtained for the large standard test system. Moreover, Figure 17 also represents the best compromise solutions which evidently portray the best positions on the pareto fronts of ISA, LISA strategy-I and LISA strategy-II.

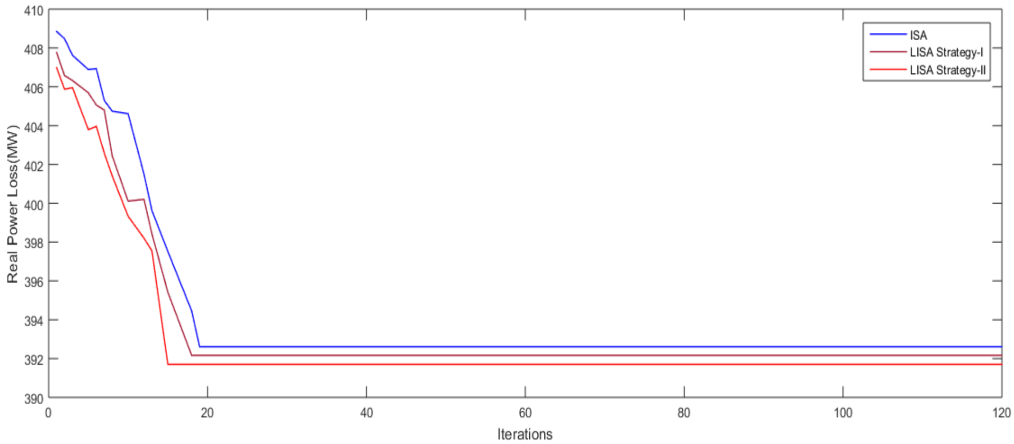

Figure 16. Convergence characteristic for IEEE 300-bus system

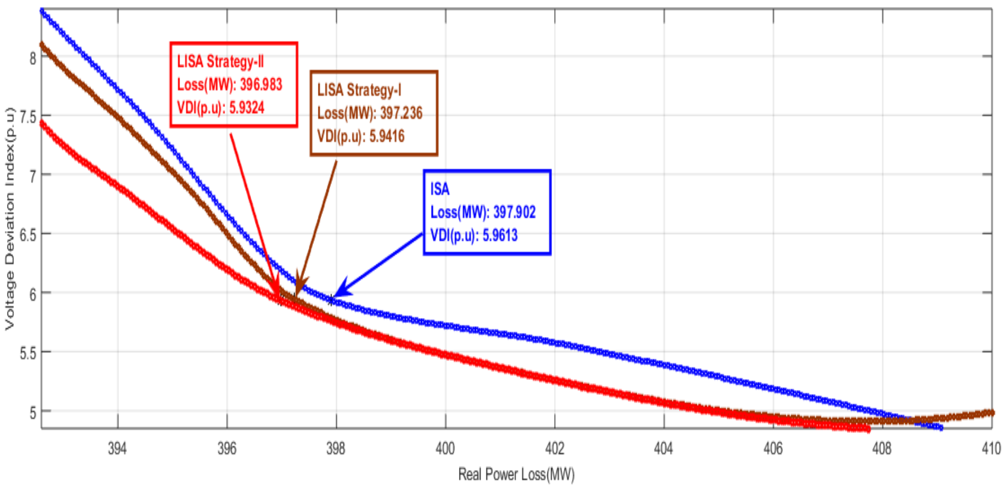

Figure 17. Best-obtained Pareto-fronts for IEEE 300-bus system

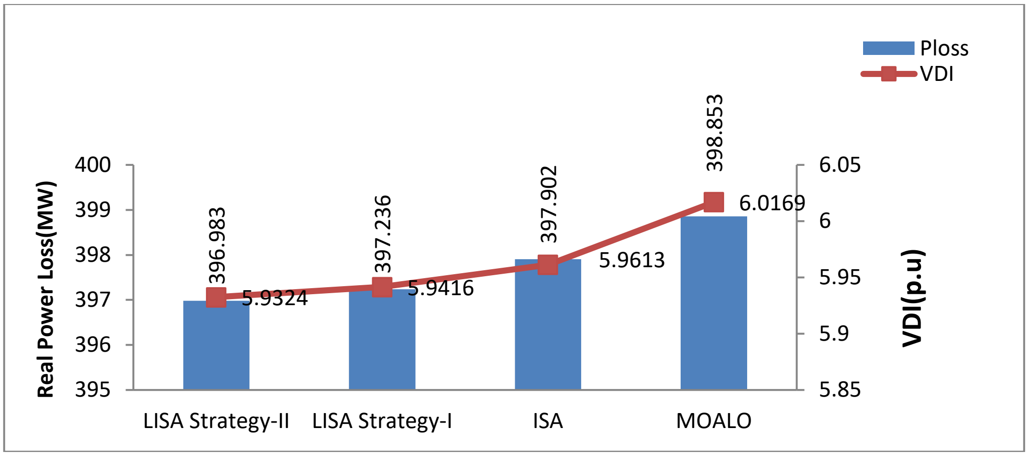

Figure 18. Comparison of optimal results for the minimization of real power loss and voltage deviation for IEEE 300-bus system

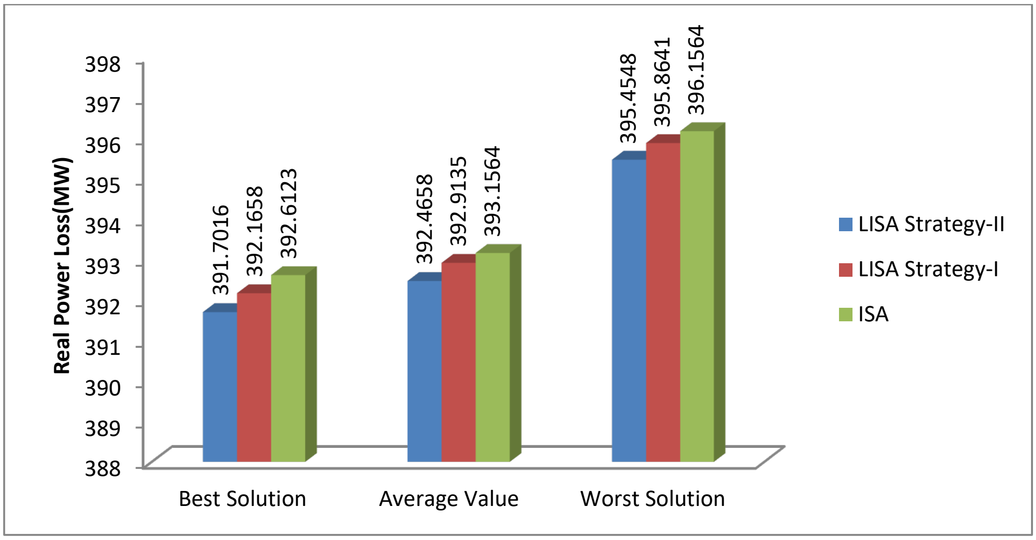

Figure 19. Statistical results obtained using ISA and LISA for IEEE 300-bus system

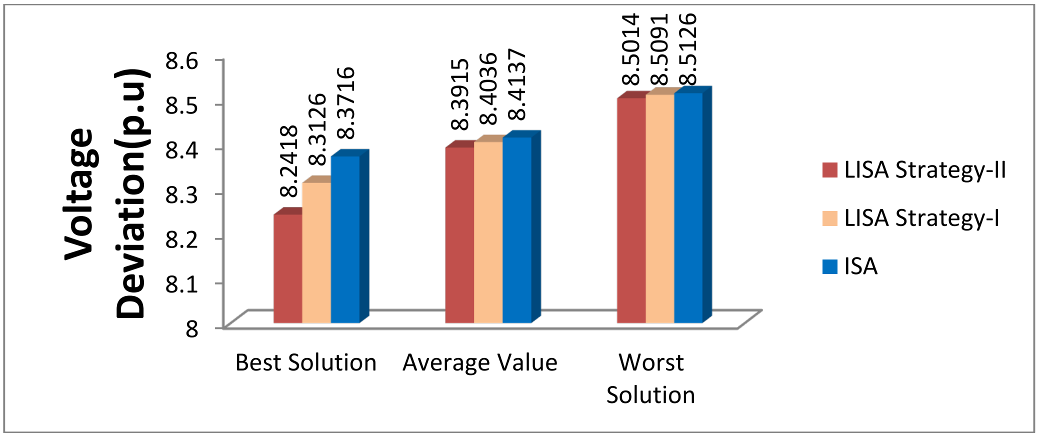

Figure 20. Statistical results obtained using ISA and LISA for IEEE 300-bus system

E. Test system 5 (IEEE 354-bus test system)

IEEE 354-bus test system, a large-scale test system is considered as the last test system to check for ORPD problem. This test system comprises 162 generating units, 27 transformers, 558 transmission lines and 42 reactive power resources. As per the study [26], these control variables' minimum and maximum limits were considered. The comprehensive data for IEEE 354-bus system is taken from [54]. The best compromise solution is presented in Figure.25 for real power loss and VDI. Figure 21 denotes the convergence features of the real power losses that were achieved from various optimization techniques using ISA, LISA strategy-I and LISA strategy-II. It can be concluded that LISA employing strategy-II provides better optimum solution compared to other optimization approaches. In addition convergence is achieved at the end of 60th iteration for LISA strategy-II. It is observed from the Figure.21 that the proposed LISA Strategy-II provides steady and fast convergence when compared to LISA Strategy-I and ISA. The proposed LISA Strategy-II takes less number of iterations to attain the optimal active power loss compared to LISA Strategy-I and ISA. Figures 23 and 24 reveals that the proposed LISA Strategy-II algorithm has the capability of determining the optimal solution rapidly and steady compared to LISA Strategy-I, ISA and the other meta-heuristic optimization techniques[52].

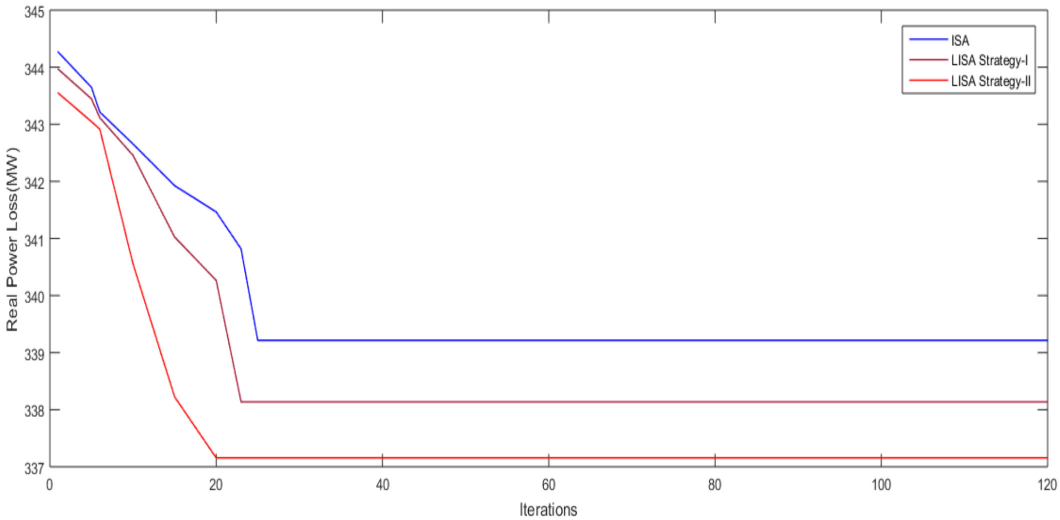

Figure 21. Convergence characteristic for IEEE 354-bus system

Simulation results reveal that LISA Strategy-II algorithm provides fast and robust performance to get rid of the optimization problems found among different power systems. Figures 23 and 24 represent the statistical comparison for 50 independent runs. Simulation results endorse the robustness of LISA Strategy-II in elucidating the ORPD problem in view of two various objective functions and in large-scale power systems, for instance 354-bus test system [52]. Figure 22 denote the distribution of Pareto-front towards reducing the real power loss and VDI for 20 independent runs for ISA, LISA strategy-I and LISA strategy-II. Consequently, regardless of the large-scale test system, the proposed LISA Strategy-II algorithm yields the finest adjustment of control variables and converges well to the Pareto optimal front with a good diversity of solutions.

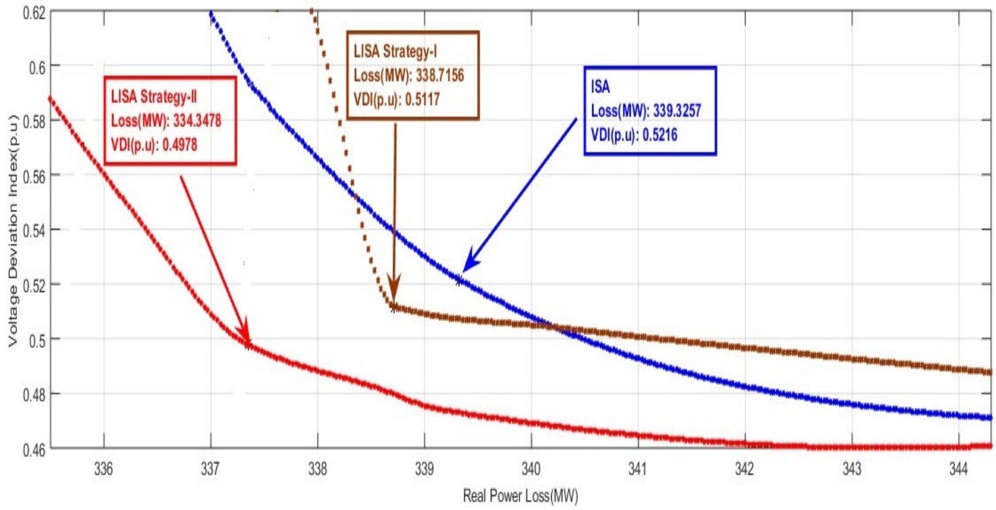

Figure 22. Best-obtained Pareto-fronts for IEEE 354-bus system

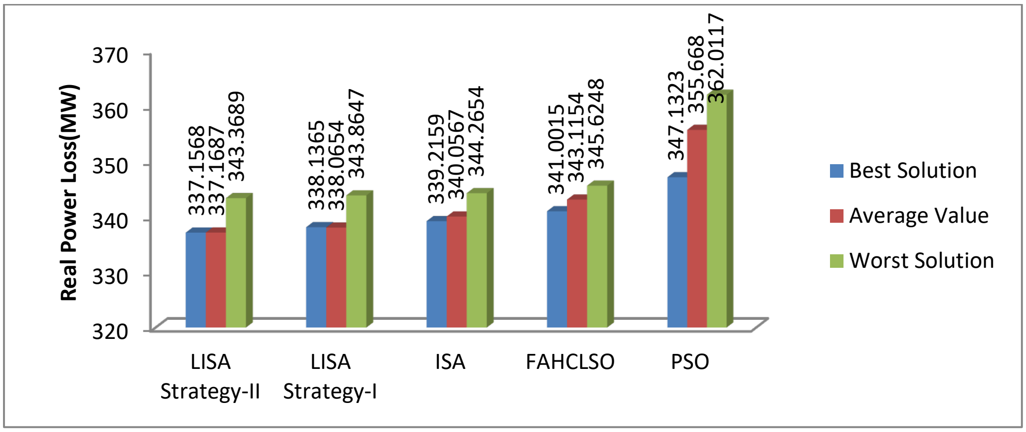

Figure 23. Comparison of simulation results for the minimization of real power loss for IEEE 354-bus system

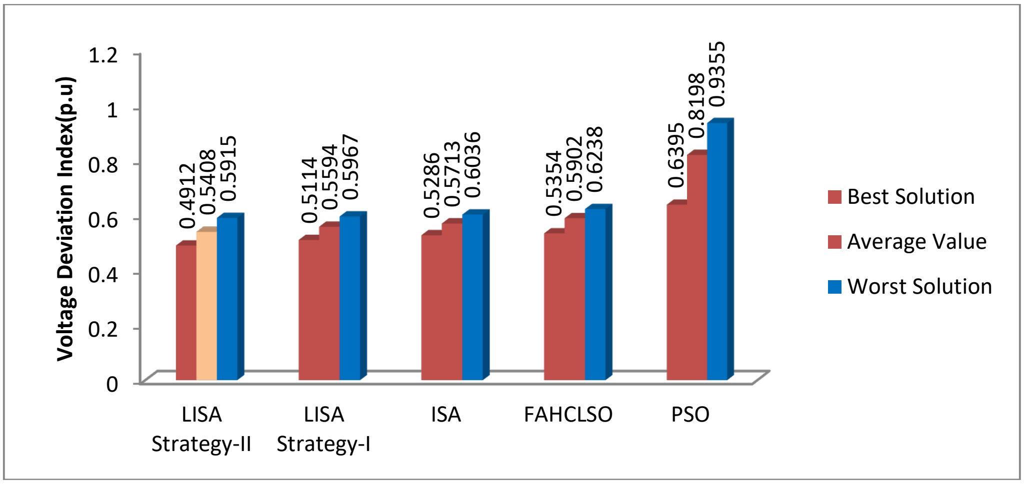

Figure 24. Comparison of simulation results for the minimization of VDI for IEEE 354-bus system

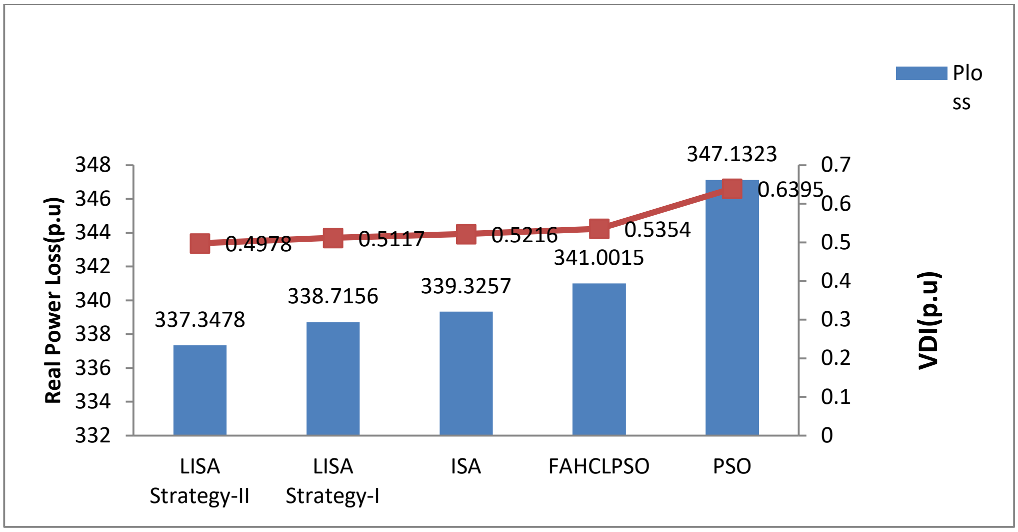

Figure 25. Comparison of simulation results for the minimization of real power loss and voltage deviation for IEEE 354-bus system

6. Conclusion

In this research article, the researchers described how LISA can be applied to overcome the ORPD problem by taking real power losses and VDI into account. This research work assess the potentials of LISA algorithm in overcoming the large-scale multi-objective ORPD problem in order to improve the power systems operational performance and reduce the losses in real power through precise fine-tuning of control variables. Being a complex multi-objective optimization problem, the ORPD problem is inclusive of different conflicting objectives as well as independent decision variables. The researchers tested the proposed algorithm in standard IEEE 30-bus, IEEE 57-bus and IEEE 118-bus test systems and in IEEE 300-bus system and IEEE 354-bus system as well. Application results obtained using LISA was contrasted with few other meta-heuristic optimization techniques for instance ISA, MOALO, MOPSO and MOEPSO. Simulation results reveals that the LISA Strategy-II is greatly effective than LISA Strategy-I, ISA, MOALO, MOPSO and MOEPSO in terms of the superiority of attained optimum solutions and computational time. Furthermore, application results evidently substantiate the efficacy of LISA Strategy-II to create a set of Pareto optimal solutions. The study results inferred the fact that the proposed LISA Strategy-II algorithm has an upright capability to overcome the delicate multi-objective optimization problem even in case of large-scale power systems. So, the LISA algorithm can be accredited as an efficient tool in the elucidation of various delicate optimization problems for future researchers. The future scope of this work may be extended to cost reduction incurred by the system operator to generators when supplying the required reactive power support with the presence of intermittent sources. LISA is robust and it has higher execution time compared to other optimization techniques. Moreover, LISA seeks for the global optimal solution by hitting a fine steadiness amongst exploration and exploitation progressions. LISA can be employed to elucidate large-scale power system optimization problems.

7. References

[1]. M. Shahidehpour, N.I. Deeb, An overview of the reactive power allocation in electric power systems, *Electric Power Components and Systems*, Vol.18, pp.495-518, 1990.

[2]. I. Kenji, Reactive power optimization by genetic algorithm, *IEEE Transaction on Power Systems* Vol.9, pp.685-692, 1994.

[3]. Mamandur KRC, Chenoweth RD. Optimal control of reactive power flow for improvements in voltage profiles and for real power loss minimization. *IEEE Trans Power Apparat Syst* Vol.7, pp.3185–93, 1981.

[4]. Wu QH, Ma JT, Power system optimal reactive power dispatch using evolutionary programming, *IEEE Trans Power Syst*., Vol.10, pp.1243–1249, 1995.
[5]. A. Saraswat, A. Saini, Multi-objective optimal reactive power dispatch considering voltage stability in power systems using HFMOEA, *Engineering Applications of Artificial Intelligence* Vol.26, pp.390-404, 2013.
[6]. M.R. Narimani, A. Azizivahed, R. Azizpanah-Abarghooee, M. Javidsharifi, Enhanced gravitational search algorithm for multi-objective distribution feeder reconfiguretion considering reliability, loss and operational cost, *IET Generation, Transmission and Distribution*, Vol.8 pp. 55-69, 2014.
[7]. T. Niknam, M.R. Narimani, J. Aghaei, R. Azizpanah-Abarghooee, Improved particle swarm optimisation for multi-objective optimal power flow considering the cost, loss, emission and voltage stability index, *IET Generation, Transmission and Distribution*, Vol.6, pp.515-527, 2012.
[8]. Hobson E. Network constrained reactive power control using linear programming. *IEEE Trans Power Syst* 1980; PAS-99(4):868–77.
[9]. Khaled Zehar, Samir Sayah, Optimal power flow with environmental constraint using a fast successive linear programming algorithm: Application to the Algerian power system, *Energy Conversion and Management*, Vol.49, pp.3361-3365, 2008.
[10]. Mangoli MK, Lee KY. Optimal real and reactive power control using linear programming. *Electr Power Syst Res* 1993; 26:1–10.
[11]. Zhua JZ, Xiong XF. Optimal reactive power control using modified interior point method. Electr Power Syst Res 2003;66(2):187–92.
[12]. K. L. Lo, S. P. Zhu, A Decoupled Quadratic Programming Approach for Optimal Power Dispatch, *Electric Power System Research*, Vol. 22, pp.47-60, 1991.
[13]. V. A.de Sousa, L. C. T. Nunes, E. A. Belati, G. R. M. da Costa, A New Approach Type-Newton For Optimal Reactive Dispatch Problem, *IEEE Power Engineering Society General Meeting*, 2003.
[14]. S. Durairaj, D. Devaraj, P.S. Kannan, Genetic algorithm applications to optimal reactive power dispatch with voltage stability enhancement, *J. Inst. Eng. India Part El Electr. Eng*. Div. Vol.87, No.42, 2006.
[15]. Q.H. Wu, Y.J. Cao, J.Y. Wen, Optimal reactive power dispatch using an adaptive genetic algorithm, Int. J. Electr. Power Energy Syst., Vol.20, pp.563–569, 2006.
[16]. Yan W, Liu F, Chung C, Wong K. A hybrid genetic algorithm-interior point method for optimal reactive power flow, *IEEE Trans Power Syst*., Vol.21, pp.1163–1169, 2006.
[17]. A. A. Abou El Ela, M. A. Abido, S. R. Spea, Optimal power flow using differential evolution algorithm, Electrical Engineering, Vol.91, pp.69-78, 2009.
[18]. A.A. Abou El Ela, M.A. Abido, S.R. Sepa, Differential evolution algorithm for optimal reactive power dispatch. Electric Power Systems Research, Vol.81, pp.458-464, 2011.
[19]. Youcef Amrane, Mohamed Boudour, Ahmed Amine Ladjici, Ali Elmaouhab, Optimal VAR control for real power loss minimization using differential evolution algorithm, Electrical Power and Energy Systems, Vol.66, pp.262-271, 2015.
[20]. M. Basu, Quasi-oppositional differential evolution for optimal reactive power dispatch, Electrical Power and Energy Systems, Vol.78, pp.29-40, 2016.
[21]. R.P. Singh, V. Mukherjee, S.P. Ghoshal, Optimal reactive power dispatch by particle swarm optimization with an aging leader and challengers, Applied Soft Computing, Vol.29, pp.298-309, 2015.
[22]. Mehdi Mehdinejad, Behnam Mohammadi-Ivatloo, Reza Dadashzadeh-Bonab, Kazem Zare, Solution of optimal reactive power dispatch of power systems using hybrid particle swarm optimization and imperialist competitive algorithms, Electrical Power and Energy Systems, Vol.83, pp.104-116, 2016.
[23]. Jirawadee Polprasert, Weerakorn Ongsakul, Vo Ngoc Dieu, Optimal Reactive Power Dispatch Using Improved Pseudo-gradient Search Particle Swarm Optimization, *Electric Power Components and Systems*, Vol.0, pp.1-15, 2016.

[24]. Mojtaba Ghasemi, Mahdi Taghizadeh, Sahand Ghavidel, Jamshid Aghaei, Abbas Abbasian, Solving optima lreactive power dispatch problem using a novel teaching–learning-based optimization algorithm, *Engineering Applications of Artificial Intelligence*, Vol.39, pp.100-108, 2015.
[25]. B. Mandal, P.K. Roy, Optimal reactive power dispatch using quasi-oppositional teaching learning based optimization, *Electrical Power and Energy Systems*, Vol.53, pp.123-134, 2013.
[26]. M. Granada, M.J. Rider, J.R.S. Mantovani, M. Shahidehpour, A decentralized approach for optimal reactive power dispatch using a Lagrangian decomposition method, *Electric Power Systems Research*. Vol.89, pp.148-156, 2012.
[27]. R. Arul, G. Ravi, S. Velusami, Non-convex economic dispatch with heuristic load patterns, valve point loading effect, prohibited operating zones, ramp-rate limits and spinning reserve constraints using harmony search algorithm, *Electrical Engineering*, Vol.95, pp.53-61, 2012.
[28]. R. Arul, G. Ravi, S. Velusami, An improved harmony search algorithm to solve economic load dispatch problems with generator constraints, *Electrical Engineering*, Vol.95, pp.53-61, 2013.
[29]. R. Arul, G. Ravi, S. Velusami, Solving Optimal Power Flow Problems Using Chaotic Self-adaptive Differential Harmony Search Algorithm, *Electric Power Components and Systems*, Vol.48, pp.782-805, 2013.
[30]. A.H. Khazali, M. Kalantar, Optimal reactive power dispatch based on harmony search algorithm, *Electrical Power and Energy Systems*, Vol.33, pp.684-692, 2011.
[31]. K. Valipour, A. Ghasemi, Using a new modified harmony search algorithm to solve multi-objective reactive power dispatch in deterministic and stochastic models, J. AI Data Min. 5 (1) (2017) 89–100.
[32]. R. Mallipeddi, S. Jeyadevi, P.N. Suganthan, S. Baskar, Efficient constraint handling for optimal reactive power dispatch problems, *Swarm and Evolutionary Computation* 5 (2012) 28-36.
[33]. Khorsandi, A., Alimardani, A., Vahidi, B., Hosseinian, S.H, Hybrid shuffled frog leaping algorithm and Nelder-Mead simplex search for optimal reactive power dispatch, *IET Gener. Transm. Distrib*, Vol.5, pp.249-256, 2011.
[34]. A. A. Abou El-Ela, A. M. Kinawy, R. A. El-Sehiemy, M. T. Mouwafi, Optimal reactive power dispatch using ant colony optimization algorithm, *Electrical Engineering*, Vol.93, pp.103-116, 2011.
[35]. Kursat Ayan, Ulas Kilic, Artificial bee colony algorithm solution for optimal reactive power dispatch, *Applied Soft Computing*, Vol.12, pp.1477-1482, 2012.
[36]. P.K. Roy, S.P. Ghoshal, S.S. Thakur, Optimal VAR control for improvements in voltage profiles and for real power loss minimization using Biogeography Based Optimization, *Electrical Power and Energy Systems*, pp.830-838, 2012.
[37]. Duman, S., Y. Sonmez, U. Guvenc, and N. Yorukeren. (2012). Optimal Reactive Power Dispatch Using a Gravitational Search Algorithm, *IET Generation, Transmission and Distribution*, Vol.6, pp.563–76, 2012.
[38]. P. K. Roy, B. Mandal, K. Bhattacharya, Gravitational Search Algorithm Based Optimal Reactive Power Dispatch for Voltage Stability Enhancement, *Electric Power Components and Systems*, Vol.40, pp.956-976, 2012.
[39]. B. Shaw, V. Mukherjee, S.P. Ghoshal, Solution of reactive power dispatch of power systems by an opposition-based gravitational search algorithm, *Electrical Power and Energy Systems*, Vol.55, pp.29- 40, 2014.
[40]. M.H. Sulaiman, Z. Mustaffa, M.R. Mohamed, O. Aliman, Using the gray wolf optimizer for solving optimal reactive power dispatch problem, *Applied Soft Computing* 32 (2015) 286-292.

[41]. R.Arul, Dr.S.Velusami, Dr.G.Ravi, "Chaotic firefly algorithm to solve economic load dispatch problems", *International Conference on Green Computing, Communication and Conservation of Energy (ICGCE)*, pp.458-464, 2013.

[42]. A Rajan, T. Malakar, Optimal reactive power dispatch using hybrid Nelder-Mead simplex based firefly algorithm, *Electrical Power and Energy Systems*, Vol.66, pp.9-24, 2015.

[43]. Kanagasabai Lenin, Bhumanapally Ravindhranath Reddy, Munagala Suryakalavathi, Hybrid Tabu search-simulated annealing method to solve optimal reactive power problem, *Electrical Power and Energy Systems*, Vol.82, pp.87-91, 2016.

[44]. A. Rajan, T. Malakar, Exchange market algorithm based optimum reactive power dispatch, Applied Soft Computing, Vol.43, pp.320-336, 2016.

[45]. Aparajita Mukherjee, V. Mukherjee, Chaos embedded krill herd algorithm for optimal VAR dispatch problem of power system, *Electrical Power and Energy Systems*, Vol.82, pp.37-48, 2016.

[46]. Khaled ben oualid Medani, Samir Sayah, Abdelghani Bekrar, Whale optimization algorithm based optimal reactive powerdispatch: A case study of the Algerian power system, *Electric Power Systems Research*, 2017.

[47]. Rebecca Ng Shin Meia, Mohd Herwan Sulaimana, Zuriani Mustaffab, Hamdan Daniyal, Optimal reactive power dispatch solution by loss minimization using moth-flame optimization technique, *Applied Soft Computing*, Vol.59, pp.210-222, 2017.

[48]. Kadir Abaci, Volkan Yamacli, Optimal reactive-power dispatch using differential search algorithm, Electrical Engineering, Vol.99, 2017.

[49]. Gandomi AH. Interior search algorithm (ISA): A novel approach for global optimization, ISA Transactions (2014).

[50]. N.Karthik, A.K.Parvathy, R.Arul, Multi-objective economic emission dispatch using interior search algorithm, *International Transactions on Electrical Energy Systems*, Vol.29,2019.

[51]. Karthik, N. Parvathy, A.K. Arul, R. Jayapragash, R. Narayanan, S., Economic load dispatch in a microgrid using Interior Search Algorithm, *Proceedings of IEEE International Conference on Innovations in Power and Advanced Computing Technologies*, i-PACT 2019 22-23 March 2019, Vellore Institute of Technology, Vellore.

[52]. Ehsan Naderi, Hossein Narimani, Mehdi Fathi, Mohammad Rasoul Narimani, A Novel Fuzzy Adaptive Configuration of Particle Swarm Optimization to Solve Large-Scale Optimal Reactive Power Dispatch, *Applied Soft Computing*, 2017.

[53]. The IEEE 57-Bus Test System [online], available at http://www.ee. washington.edu/research/pstca/pf57/pg_tca57bus.htm.

[54]. PSTCA, Power Systems Test Case Archive, University of Washington, Available: http://www.ee.washington.edu/research/pstca/, 2016 (accessed 29.10.10).

[55]. The IEEE 118-Bus Test System [online], available at http://www.ee. washington.edu/research/pstca/pf118/pg_tca118bus.htm

[56]. Souhil Mouassa, Tarek Bouktir, Multi-objective ant lion optimization algorithm to solve large-scale multi-objective optimal reactive power dispatch problem, COMPEL: The *International Journal for Computation and Mathematics in Electrical and Electronic Engineering*, Vol. 35 No. 1, pp. 350-372, 2018.

[57]. Gonggui Chen, Lilan Liu, Yanyan Guo, Shanwai Huang, Multi-objective enhanced PSO algorithm for optimizing power losses and voltage deviation in power systems, COMPEL: *The International Journal for Computation and Mathematics in Electrical and Electronic Engineering*, Vol. 35 No. 1, pp. 350-372, 2016.

[58]. Zimmerman, R.D., Murillo Sanchez, C.E. and Thomas, R.J., “MATPOWER: Steady-State operations, planning, and analysis tools for power systems research and education, power systems”, *IEEE Transactions on Power Systems*, Vol. 26 No. 1, pp. 12-19, 2011.

[59]. Mohseni-Bonab SM, Rabiee A, Jalilzadeh S, Mohammadi-Ivatloo B, Nojavan S. Probabilistic multi objective optimal reactive power dispatch considering load uncertainties using Monte Carlo simulations. *J Oper Autom Power Engg*.; Vol. 3, No.1:83–93. 2015.

[60]. Deb K. Multi-objective optimization using evolutionary algorithms, John Wiley & Sons; 2001.

[61]. Mohseni-Bonab SM, Rabiee A, Mohammadi-Ivatloo B. Voltage stability constrained multi-objective optimal reactive power dispatch under load and wind power uncertainties: a stochastic approach. *Renew Energy*, Vol.85: 598–609, 2016.

[62]. Rabiee A, Soroudi A, Mohammadi-Ivatloo B, Parniani M. Corrective voltage control scheme considering demand response and stochastic wind power. *IEEE Trans Power Syst.*; 29:2965–73, 2014.

[63]. Seyed Masoud Mohseni-Bonab, Abbas Rabiee, Behnam Mohammadi-Ivatloo, Saeid Jalilzadeh, Sayyad Nojavan, A two-point estimate method for uncertainty modeling in multi-objective optimal reactive power dispatch problem, *Electrical Power and Energy Systems*, vol.75, pp.194-204, 2016.

[64]. Hakli H and Uguz H, A novel particle swarm optimization algorithm with Levy flight, *Applied Soft Computing*, vol.23, no.1, pp.333-345, 2014.

Karthik Nagarajan received his B.E. Degree in Electrical and Electronics Engineering from University of Madras in 2000 and M.E. Degree from Anna University, Chennai, India in 2005.He worked as an Assistant Professor in Adhiparasakthi Engineering College, Melmaruvathur, India. Presently he is an Assistant Professor with the Department of Electrical and Electronics Engineering, Hindustan Institute of Technology and Science, Chennai. Currently he is pursuing his Ph.D. degree at Hindustan Institute of Technology and Science, Chennai, India. He has published around 12 papers in International and National Journals and Conference Proceedings. His main research interests include Power System Optimization, Renewable Energy Sources and Smart Grid.

Ayalur Krishnamoorthy Parvathy received her B.Tech. and M.Tech. degrees from Calicut University, India, in 1993 and 1998 respectively. She obtained Ph.D. in Advanced Control of PMSM from Anna University, Chennai, India in 2013. She is serving as Professor & Head of Department, Department of EEE, Hindustan Institute of Technology and Science, and Chennai. She has published around 36 papers in International and National journals and conference proceedings. Her research interests are linearization, motion control and renewable energy sources.

Arul Rajagopalan received his B.Tech. and M.Tech. degrees from Annamalai University, Chidambaram, India. He obtained Ph.D. in Power Systems from Annamalai University, Chidambaram, India in 2015. He is serving as Associate Professor, School of Electrical Engineering, Vellore Institute of Technology, Chennai Campus, Chennai. He has published around 32 papers in International and National journals and conference proceedings. His research interests include Power System Optimization, Renewable Energy Sources and Smart Grid.