Application of Improved Seagull Optimization Algorithm on Optimal Allocation Optimizations of Distributed Generation

Jie Qian*, Yuhan Peng, Haoling Zheng, and Xi Wang

***Abstract*—Optimal allocation optimization (OAO) research is an important technology to construct new distribution networks (DNs) with environmental protection and high efficiency. The OAO research in this paper aims to achieve the more ideal operation of DNs by exploring superior allocation schemes including the optimal power factor, access node and capacity of distributed generations (DGs). In order to solve the complex OAO problems, an improved seagull optimization algorithm with elite reserve (ISOAE) is proposed and applied to two different OAO scenarios. In traditional OAO cases with constant loads, the suggested ISOAE finds better DG allocation schemes with less power loss than the basic seagull optimization algorithm (BSOA) and multiple published algorithms. Simulation experiments show that the number, location, capacity and power factor of DGs all have a non-negligible impact on the operation of DNs. In OAO cases with practical seasonal loads, the access of traditional generator (CG), renewable distributed generators represented by photovoltaic (PV) and wind turbine (WT) into the DNs is studied. Multiple experiments on the IEEE 33-bus network demonstrate that CG achieves the relatively best operation status than PV and WT. However, considering resource conservation and environmental protection, renewable PV and WT are more favored by actual power grids. Furthermore, WT operating at the optimal power factor is superior to the PV with uneven radiation intensity distribution in reducing daily active energy loss and increasing node voltage of DNs. In general, the reasonable integration of renewable energy such as WT is of great significance for achieving the two-carbon strategy of power grids.**

***Index Terms*—Seagull optimization algorithm, Renewable energy, Optimal allocation, Wind turbine**

I. Introduction

THE rapidly growing energy demand may cause a variety of adverse effects on the normal operation of distribution networks (DNs), such as increased power loss and poor supply reliability. Distributed generation (DG) is usually introduced into DNs to relieve the power supply pressure of traditional power grids. The optimal allocation optimization (OAO) research in this paper aims to realize the efficient, economical and environmental friendly operation of DNs by exploring high-quality DG allocation schemes. However, it is worth noting that the improper access of DG may lead to some negative effects such as decreased power quality and higher cost. Therefore, this paper aims to propose an innovative technology that can effectively solve OAO problems and provide superior DG allocation schemes.

A. Literature review

In recent years, scholars and power enterprise workers have paid great attention to the research on improving the safety and economy of DNs through DG connection [1-3]. Intelligent algorithms such as artificial hummingbird algorithm [4], northern goshawk optimization algorithm [5] and decomposition based evolutionary algorithm [6] play a non-negligible role in solving the non-convex OAO problems. Published literatures state that there are three main ways of DG integration to achieve better operating state of DNs.

(*i*) Integration of DG operating at unit power factor

The whale optimization algorithm in Ref. [7] was applied to minimize power loss and improve voltage profile by introducing the DG operating at unit power factor (UPF) for real power injection. Based on the DG integration, an improved raven roosting optimization algorithm with game theory enhanced the technical and economic benefits of distributed systems [8]. In Ref. [9], a particle swarm optimization algorithm with orientation and shrinking factor found the location and capacity allocation schemes of DGs at UPF and smoothly reduced power loss of three DNs.

(*ii*) Combined integration of DG and shunt capacitor

It is notable that the DG running at UPF can only provide real power. Reasonable reactive power compensation is conducive to improve the power quality and supply efficiency. Compared to the individual application of DG running at UPF, the combined application of DG and the shunt capacitor (SC) for reactive power injection has received more attention.

Ref. [10] presented multi-objective evolutionary algorithm based on decomposition, which was effective to reduce the real/reactive power losses based on the optimal configuration of DGs and SCs. In Ref. [11], a butterfly algorithm with constriction factor and modified local search pattern was put forward. It found feasible DG/SC configuration schemes and minimized the active power loss of three different DNs.

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Furthermore, a modified gravitational search algorithm with strong exploration capability realized the reduction of active power loss and voltage deviation through the rational configuration of DG and SC [12].

(*iii*) Integration of DG operating at optimal power factor

Existing studies have proved that the combined application of DG and SC can obtain a more ideal operating state of DN than the individual configuration of DG running at UPF. More importantly, DG can operate at desired power factor with appropriate cooperation of inverters or converters according to IEEE 1547 standard. In other words, the DG operating at optimal power factor (OPF) can provide both active and reactive compensation injections for DNs.

At present, scholars have carried out extensive research on determining the optimal power factor of DGs. To optimize the power loss and supply reliability of DNs, Ref. [13] proposed a methodology combining symbiosis organism search and neural network algorithm. In Ref. [14], genetic algorithm and particle swarm optimization were presented and applied to search the optimal locations, sizes, and power factors of DGs. And its availability had been verified by several experiments on the IEEE 33-bus DN.

B. Motivation and contribution

It is not difficult to find that compared with the combined application, DG operating at OPF can achieve the similar operation status on DNs and avoid the SC configuration cost. Therefore, the OAO research in this paper is conducted based on the third type of DG configuration. Specifically, in addition to the number, access node and capacity of DG, this paper also takes the OPF of DG as an adjustable control variable of OAO research.

Due to the simultaneous existence of continuous and discrete control variables, it is difficult for traditional methods to solve OAO problems. Fortunately, advanced computer technologies such as intelligent algorithms provide efficient tools for solving complex engineering optimization problems such as OAO. This paper also chooses a swarm intelligence algorithm, i.e., seagull optimization algorithm (SOA), to explore superior DG allocation schemes. Compared with the existing studies, the main contributions of this paper for solving complex OAO problems are as follows.

- An improved seagull optimization algorithm with elite reserve (ISOAE) is presented for the first time to explore the competitive DG configuration schemes including location, capacity and power factor. Several OAO simulation experiments demonstrate that ISOAE achieves better DG schemes than the basic seagull optimization algorithm (BSOA).
- Different from most OAO studies conducted only on standard IEEE distribution systems, this paper further discusses the OAO studies on an actual power grid model that considers hourly load variation. And the proposed ISOAE is applied to solve the OAO problem on the actual DN model with the goal of reducing daily active energy loss.
- In addition to the traditional generator (CG), this paper focuses on the application of renewable energy such as photovoltaic (PV) and wind turbine (WT) in the optimal allocation problems of distribution systems. The renewable DG configuration scheme obtained by the proposed ISOAE helps to achieve the 2050 carbon neutral goal.

C. Structure

The remainder of this paper is organized as follows. The mathematic model of OAO problem, which consists of objective functions and system constraints, is described in Section II. Meanwhile, Section II also gives the novel ISOAE proposed to determine the high-performance DG allocation schemes of OAO problems. The two distribution network models involved in this paper, including a standard radial distributed network with constant load/generation and the other one with practical seasonal load and variable generation, are presented in Section III. Multiple OAO simulation experiments to verify the applicability of BSOA and the competitive edge of ISOAE are described in detail in Section IV. And Section V gives the conclusion.

II. Mathematical Model and Proposed Technology

In essence, the OAO problem is a minimal optimization problem with multiple constraints. OAO problems have nonlinear and non-convex characteristics, as well as both discrete and continuous control variables, making it difficult to solve. In this paper, intelligent algorithms represented by ISOAE are adopted to explore the advantageous DG configuration schemes of OAO problems. The mathematical model of OAO problem and the innovative ISOAE are described in detail in this section.

A. OAO model

As a representative engineering problem in the field of distribution network optimization and expansion, the mathematical model of OAO problem consists of objective functions and system constraints.

1) Objectives

The OAO problem studied in this paper mainly involves two optimization objectives, i.e., active power loss (APL) and daily active energy loss (DAEL) [12, 14]. The APL of DN system in kW can be calculated as formula (1). The relevant variables are intuitively explained in a single line of radial DN shown in Fig. 1. In addition, the DAEL in kWh can be calculated based on formulas (2) and (3).

$$APL_{(T)}=\sum_{k=1}^{N_{line}} I_{(T)k,k+1}^{2} R_{k,k+1} \tag{1}$$

$$AEL_{(\Delta T)}=APL_{(\Delta T)}\times \Delta T \tag{2}$$

$$DAEL=\sum_{T=1}^{24} APL_{(T)} \tag{3}$$

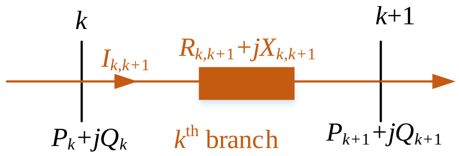

Fig. 1. A single line in radial DN

where $I_{(T)k,k+1}$ is the current in kA of kth line at time T. Q_k is the reactive power of the k^{th} line while P_k is the active one. $R_{k,k+1}$ and $X_{k,k+1}$ are the equivalent resistance and reactance of the k^{th} line. N_{line} is the number of branches in the DN system. AEL is active energy loss in kWh during $\varDelta T$ and $\varDelta T$ =1 hour in this paper.

2) Constraints

The OAO problem is an optimization problem strictly limited by multiple system constraints. The premise of the further optimization of DN operation is to ensure the safety and stability of power grids. In other words, every feasible DG allocation scheme should meet all system constraints shown in formulas (4) ~ (8) [11, 12, 14].

(*i*) Power balance

The distribution network introducing DGs should still achieve the active power balance shown in formula (4) and the reactive one shown in formula (5).

$$P_{sup}+\sum_{i=1}^{N_{dg}}P_{dg,i}=\sum_{j=1}^{N_n}P_{load,j}+\sum_{k=1}^{N_{line}}P_{loss,k} \tag{4}$$

$$Q_{sup}+\sum_{i=1}^{N_{dg}}Q_{dg,i}=\sum_{j=1}^{N_n}Q_{load,j}+\sum_{k=1}^{N_{line}}Q_{loss,k} \tag{5}$$

where P_{sub} and Q_{sub} are the active power and reactive one supplied by substation. $P_{dg,i}$ and $Q_{dg,i}$ respectively indicate the active and reactive power injected by the i^{th} DG operating at OPF. $P_{load,j}$ and $Q_{load,j}$ are the active and reactive power of load demand at the j^{th} node. $P_{loss,k}$ and $Q_{loss,k}$ are the active and reactive power loss at the k^{th} line. N_{dg} and N_n are the numbers of DGs and nodes.

(*ii*) Node voltage

The node voltage of DN is limited to the allowable range shown in formula (6).

$$V_i^{\min}\le V_i\le V_i^{\max}\ ,\ i=1,2,\cdots,N_n \tag{6}$$

where V_i^{min} is the minimum voltage and set as 0.9 p.u. in this paper while V_i^{max} is the maximum one and set as 1.05 p.u..

(*iii*) Injected active capacity

To maintain the balance between loads and generations, the total injected active capacity connected into DNs cannot exceed a certain proportion of the total load of power system. In this paper, the total capacity of DGs is limited according to formula (7).

$$\sum_{i=1}^{N_{dg}}P_{dg,i}\le f_{dg}\times\sum_{j=1}^{N_n}P_{load,j} \tag{7}$$

where f_{dg} indicates the maximum allowable factor of DGs, which is set as 0.8 in this paper.

(*iv*) Power factor

In this paper, the power factor of each DG is limited within the range of 0.8~1 according to formula (8).

$$0.8\le OPF\le 1 \tag{8}$$

Furthermore, DGs cannot be connected at the balance node of DN and multiple DGs cannot be accessed at the same node. The DG allocation scheme that does not meet any of the above constraints is unqualified scheme. Unqualified schemes will be first excluded during the iterative process of ISOAE when solving OAO problems.

B. Basic seagull optimization algorithm

SOA is a swarm intelligence algorithm inspired by biological behaviors of seagull population such as migration and attack [15, 16]. The standard and improved SOA have successfully solved complex power grid optimizations such as economic planning [17, 18] and power quality improvement [19], showing the great potential to solve OAO problems.

In this paper, the BSOA is innovatively applied to explore the feasible DG allocation schemes of OAO problem aimed at reducing the APL and DAEL goals. BSOA completes the migration of seagull individuals according to formulas (9) ~ (11), and then carries out the attack and foraging according to formulas (12) ~ (16), so as to obtain the updated position of seagull population [15].

$$Ds=\left|A*P_s(k)+B*(P_{best}(k)-P_s(k))\right| \tag{9}$$

$$A=f_c-(k*f_c/k_{\max}) \tag{10}$$

$$B=2*A^2*f_{rand} \tag{11}$$

where *A* represents the movement behavior of search agent in a given search space and *B* is used to for the suitable balance between exploration and exploitation. $P_s(k)$ indicates the current position of seagull individual at the *k*th iteration and P_{best} is the optimal position of seagull population. k_{max} is the number of maximum iteration and f_c is responsible for the dynamic change of *A*. f_{rand} is a random number within [0,1].

$$x=R_{sp}*\cos\theta \tag{12}$$

$$y=R_{sp}*\sin\theta \tag{13}$$

$$z=R_{sp}*\theta \tag{14}$$

$$R_{sp}=u*e^{\theta v} \tag{15}$$

$$P_s(k)=Ds*x*y*z+P_{best}(k) \tag{16}$$

After completing migration behavior, seagull individuals will carry out spiral attack behavior by constantly changing the angle θ and radius R_{sp}. The position of seagull individual in spiral motion is shown as *x*, *y* and *z*. θ is a random number within [0,2 π] and the two coefficients i.e., *u* and *v*, are used to control R_{sp}. The updated position of seagull population after performing migration and foraging is shown in formula (16). And the other parameters of BSOA are described in detail in Ref. [15, 20].

C. Improved seagull optimization algorithm

The applicability of BSOA to solve OAO problems is proved by simulation experiments on standard DNs. However, compared with the existing algorithms, the performance of BSOA in solving allocation problems of DNs has room for further improvement. According to the characteristics of OAO, ISOAE which integrates the re-update operation of weak seagull and the reserve population of elite seagull is proposed.

When solving the specific OAO problems, the optimization objectives such as APL are adopted as the fitness of ISOAE to determine the weak seagull individuals. In this paper, each seagull individual, i.e., each allocation scheme of OAO, includes the corresponding access node, capacity, and power factor of N_{dg} DGs. ISOAE mainly updates the inferior allocation schemes based on the published elite schemes to obtain the more ideal DG allocation schemes than BSOA. In this paper, 10%N_p seagull individuals with the greater APL are defined as the inferior allocation schemes and N_p is the size of seagull population. The elite reserve population consists of potential DG access nodes published in recent literatures. The inferior schemes select the DG location from the elite reserve population and randomly generate the DG capacity and power factor, thus forming the re-exploration population of ISOAE. The updated population at the current iteration is determined by integrating the re-exploration population and the remaining seagull population that eliminates inferior individuals. The scheme with the minimum APL obtained after the maximum iteration is the finally-adopted DG allocation scheme determined by the presented ISOAE. The main process of ISOAE to solve OAO problems with APL reduction as an example is shown in Fig. 2.

III. Application Scenario

This paper verifies the significant advantages of the proposed technology in solving OAO problems under two distribution network models. Similar to the vast majority of published OAO studies, this paper explores the DG configuration schemes with controllable power output on the standard IEEE 33-bus DN with constant loads. Additionally, the OAO research on a DN with seasonal loads in domestic area, which considers the allocation of three types of DGs including CG, PV and WT, is discussed as well.

A. DN model with constant load/generation

The standard IEEE 33-bus DN is a test distribution system frequently used in OAO research. The OAO simulation experiments on the 33-bus DN can provide quantitative comparison results between the proposed ISOAE and published algorithms, so as to enhance the persuasiveness of ISOAE. Fig. 3 and Table I respectively give the structure and details of the standard 33-bus DN. Supplementary data on this distribution system can be found in Ref. [5, 12, 14]. In this paper, the OAO simulation experiments aimed at achieving the minimum active power are carried out on this DN with constant loads. The active power loss of the original 33-bus DN, i.e., 211kW, will be reduced by determining the OPF, access node and capacity allocation schemes through the suggested ISOEA.

B. DN model with seasonal load

In addition to the regular OAO research on standard DNs, this paper also conducts the more in-depth OAO study on a more complex DN that considers the actual user load in a certain area inside the country. Table II shows the hourly loads of each season in this specific area and obtains the hourly load variation curve shown in Fig. 4 based on this. The ordinate of Fig. 4 indicates the load value at the corresponding moment as a percentage of the peak load, which is actually the average of seasonal loads.

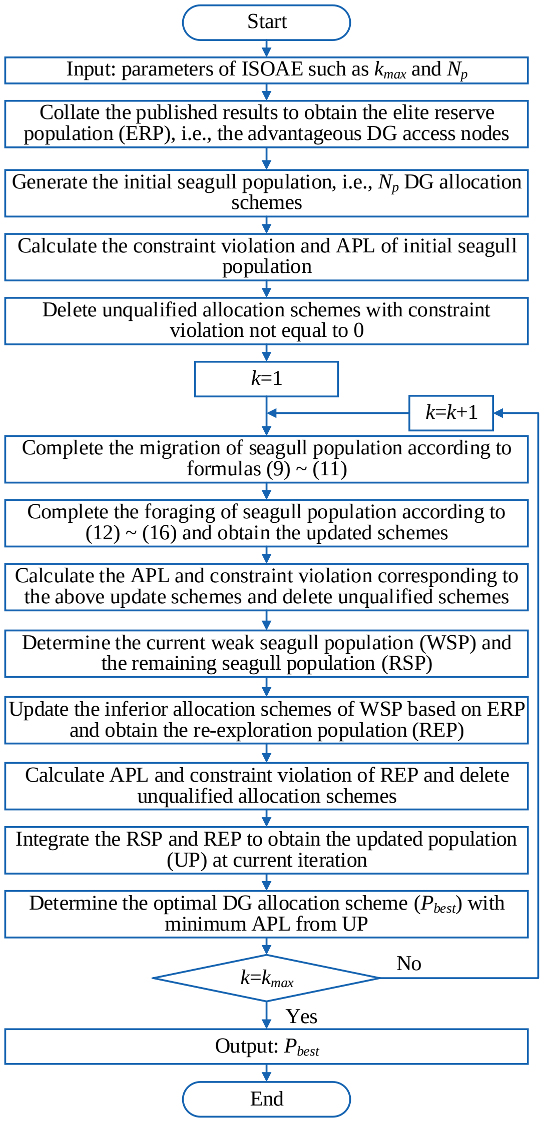

Fig. 2. Flow chart of ISOAE in solving OAO problems

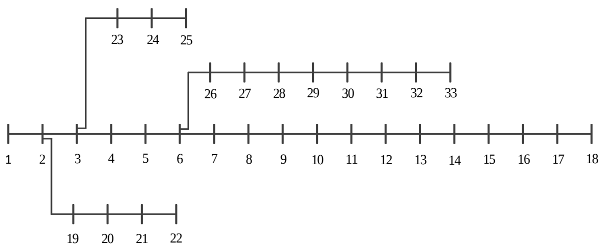

Fig. 3. Single line diagram of IEEE 33-bus system

TABLE I
Details of IEEE 33-bus System

Main information of IEEE 33-bus DN	
Number of nodes	33
Number of branches	32
Total active load	3.7MW
Total reactive load	2.3Mvar
Active power loss	211kW
Reactive power loss	143.1kvar
Maximum node voltage/node	1p.u./Node 1
Minimum node voltage/position	0.9037p.u./Node 18
Maximum allowable active power injection	2.96MW

Furthermore, the access of three types of DGs including CG with controllable power output, PV, and WT into this DN model is discussed. Based on the seasonal output of PV and WT given in Ref. [14], the hourly output variation curve of two related renewable distributed generators shown in Fig. 5 is obtained. Fig. 5 intuitively shows that the hourly power output of WT is much more stable than that of PV. This is because although the weather condition has an inevitable impact on both PV and WT, the serious insufficient radiation intensity at night and the high radiation intensity at noon cause significant fluctuations in the hourly power generation of PV. Therefore, the WT with relatively uniform wind speed distribution is more ideal than PV in the OAO research.

The OAO research conducted on the DN model with practical seasonal loads can more comprehensively verify the performance of ISOAE in actual industrial scenarios.

IV. Experimental Verification

In the two application scenarios given in Section III, the performance of BSOA and ISOAE in solve traditional and practical OAO problems is verified. The main parameters of BSOA and ISOAE are set as follows. In this paper, N_p=50, k_{max}=100 (N_{dg}=1)/200 (N_{dg}=2) /300 (N_{dg}=3), f_c=2, u=v=1, which refer to literatures [15, 21]. Since this combination of parameter settings is capable to obtain the DG allocation schemes with competitive advantages, this paper does not provide additional discussion on parameter settings.

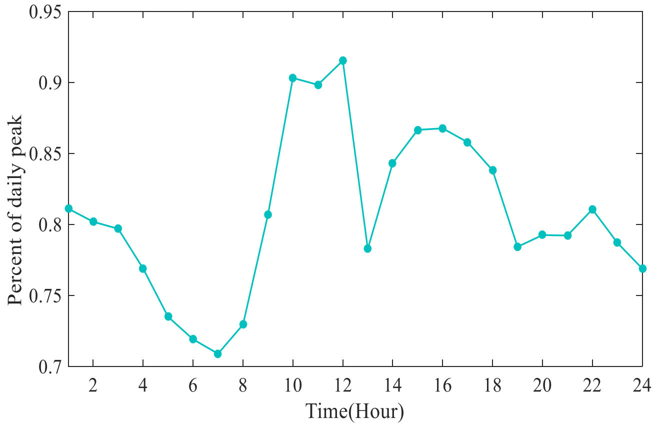

Fig. 4. Hourly load variation curve

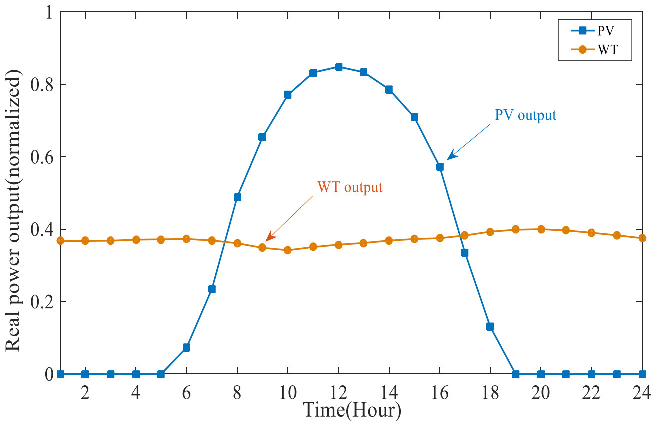

Fig. 5. Hourly output curves of PV and WT

TABLE II
Seasonal Loads

Hour	Spring	Summer	Autumn	Winter
0-1	0.639426076	0.92680776	0.67826087	1
1-2	0.614472863	1	0.63826087	0.954808806
2-3	0.620087336	0.970017637	0.662608696	0.935110081
3-4	0.6069869	0.936507937	0.643478261	0.888760139
4-5	0.583281347	0.908730159	0.632173913	0.81575898
5-6	0.582657517	0.875220459	0.636521739	0.782155272
6-7	0.592638802	0.819223986	0.630434783	0.793742758
7-8	0.645664379	0.814373898	0.679130435	0.778679027
8-9	0.762944479	0.791005291	0.836521739	0.836616454
9-10	0.961946351	0.815255732	0.95826087	0.877172654
10-11	0.978789769	0.768077601	0.96	0.886442642
11-12	1	0.759700176	1	0.901506373
12-13	0.755458515	0.742945326	0.793913043	0.838933951
13-14	0.877105427	0.787477954	0.88	0.828505214
14-15	0.94073612	0.785273369	0.92	0.820393975
15-16	0.936993138	0.776455026	0.932173913	0.825028969
16-17	0.935121647	0.764550265	0.924347826	0.80764774
17-18	0.855895197	0.738536155	0.929565217	0.828505214
18-19	0.767935122	0.701499118	0.839130435	0.828505214
19-20	0.769182782	0.69973545	0.807826087	0.893395133
20-21	0.754834685	0.704144621	0.806086957	0.90382387
21-22	0.734872115	0.814373898	0.782608696	0.910776362
22-23	0.700561447	0.884920635	0.728695652	0.834298957
23-24(0)	0.68683718	0.909611993	0.715652174	0.763615295

A. OAO experiments with constant loads

As with most OAO studies, traditional OAO experiments are first conducted on the standard IEEE distribution systems. The DGs with controllable power output are adopted to reduce the active power loss of DNs. The effects of the number, location, capacity and power factor of DGs on the operating state of DNs are discussed in detail in this section.

Fig.6 shows the convergence curves obtained by the original BSOA and the novel ISOAE when different amounts of DGs are accessed. It indicates that two above algorithms are suitable for solving OAO problems aiming at reducing APL, and ISOAE achieves smaller power loss when configuring the same number of DGs. Meanwhile, Table III gives the feasible allocation schemes obtained by BSOA and ISOAE when one, two or three DG units are configured respectively. It clearly states that as the number of DGs increases, the APL of DNs decreases. And ISOAE achieves better DG allocation schemes over BSOA when the same number of DG is connected. More specifically, ISOAE reduces the APL of the 33-bus DN by 93.9603%, from 211kW to 12.7438kW, when connecting three DGs.

In addition to comparing with the BSOA without any improvement measures, Table IV also provides the more comprehensive comparison results between ISOAE and other existing algorithms. Table IV quantitatively proves that the proposed ISOAE outperforms published algorithms such as WOA [7], PSO-OS [9] and analytical approach [22], further validating the enormous potential of ISOAE in solving OAO problems. Meanwhile, Fig.7 shows the node voltage profiles of the 33-bus DN after configuring DGs according to the schemes shown in Table III. Fig.7 intuitively indicates that the DG schemes obtained by BSOA and ISOAE not only reduce the active power loss, but also effectively improves the node voltage of distribution system. Besides, compared with the original DN and the DN with one DG, the node voltage of DNs with two or three DGs has been significantly improved.

B. OAO experiments with practical loads

After validating the applicability of BSOA and ISOAE on the standard DN, the performance of the two related algorithms is further verified on the DN with actual load variation. Specifically, in addition to the traditional DGs represented by CG, this paper also discusses the integration of two typical renewable DGs, i.e., PV and WT.

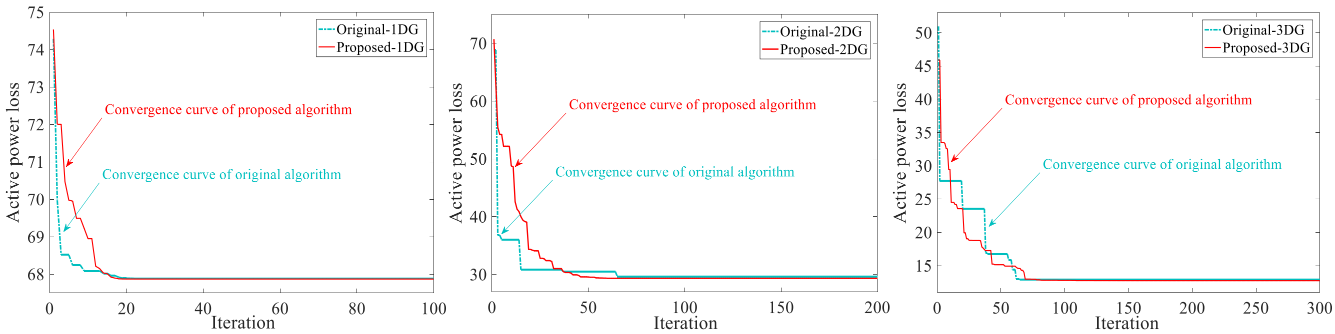

Fig. 6. Convergence curves of BSOA and ISOAE for solving OAO problems with constant loads

TABLE III
DG ALLOCATION SCHEMES ON STANDARD DN WITH CONSTANT LOADS

Algorithm	Node	Capacity/OPF	Node	Capacity/OPF	Node	Capacity/OPF	APL (kW)	Decreased percentage
N_{dg}=1								
Original	6	2558.6/0.8292					67.8866	67.8263%
Proposed	6	2558.5/0.8237					67.8688	67.8347%
N_{dg}=2								
Original	13	870.7/0.8874	30	1187.3/0.8050			29.6599	85.9431%
Proposed	13	819.0/0.8834	30	1240.4/0.8000			29.3118	86.1082%
N_{dg}=3								
Original	13	798.8/0.8914	24	959.1/0.8698	30	1164.1/0.8001	12.8910	93.8905%
Proposed	13	739.2/0.8826	24	1049.0/0.8839	30	1156.5/0.8000	12.7438	93.9603%

TABLE IV
COMPARISON RESULTS ON STANDARD DN WITH CONSTANT LOADS

Algorithm	APL (kW)	Algorithm	APL (kW)	Algorithm	APL (kW)
N_{dg}=1		N_{dg}=2		N_{dg}=3	
Original	67.8866	Original	29.6599	Original	12.8910
Proposed	67.8688	Proposed	29.3118	Proposed	12.7438
HAS-PABC [23]	68.29	ELF [24]	44.39	IPSO [25]	13.4
PSO-OS [9]	67.86	IMDE [26]	32.08	HHO [27]	14.94
WOA [7]	67.86			QODELFA [28]	15.35
Analytical approach [22]	68.0			PSO-OS [9]	12.7
				WOA [7]	16.28
				ALO [29]	27.84

1) CG access

Firstly, OAO experiments are performed on the 33-bus distribution system whose hourly load variation is shown in Fig. 4. Fig. 8 shows the convergence curves of BSOA and ISOAE for solving the OAO problems with the goal of reducing DAEL when different numbers of CG are connected. Table V provides the specific location, capacity and power factor of DG configuration schemes which obtain the minimum DAEL. As an example, when three CGs are integrated into the 33-bus DN, BSOA reduces the DAEL to 217.5995 KWh while ISOAE successfully achieves a smaller DAEL of 213.0136 KWh. Table V intuitively states that compared with BSOA, ISOAE determines higher-quality CG allocation schemes on the DN considering practical loads, proving the effectiveness of improvement measures such as elite reserve population.

2) PV access

Subsequently, the application of PV to optimize the operation status of DNs by reducing DAEL is studied. Recently, integrating PV to achieve better operating of power grids has received widespread attention [30, 31]. The hourly power output of PV in this paper is shown in Fig. 5. Fig. 9 and Table VI respectively show the convergence curves and the optimal PV allocation schemes obtained by BSOA and ISOAE after integrating different amounts of PVs. It is not difficult to find that the DAEL decreases significantly with the access of PV. Among them, when three PVs are connected, the scheme obtained by ISOAE achieves the DAEL of 1754.0288 KWh and is superior to the one obtained by BSOA with the DAEL of 1778.3426 KWh.

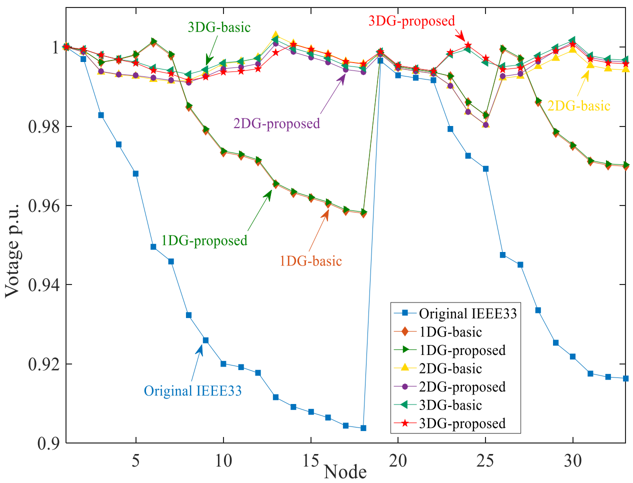

Fig. 7. Node voltage profiles on standard DN with constant loads

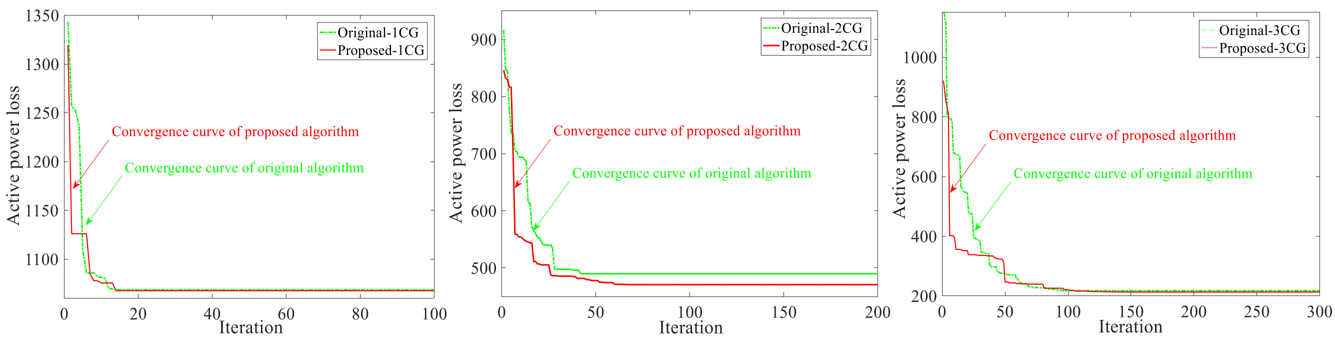

Fig. 8. Convergence curves of practical OAO problems with CG access

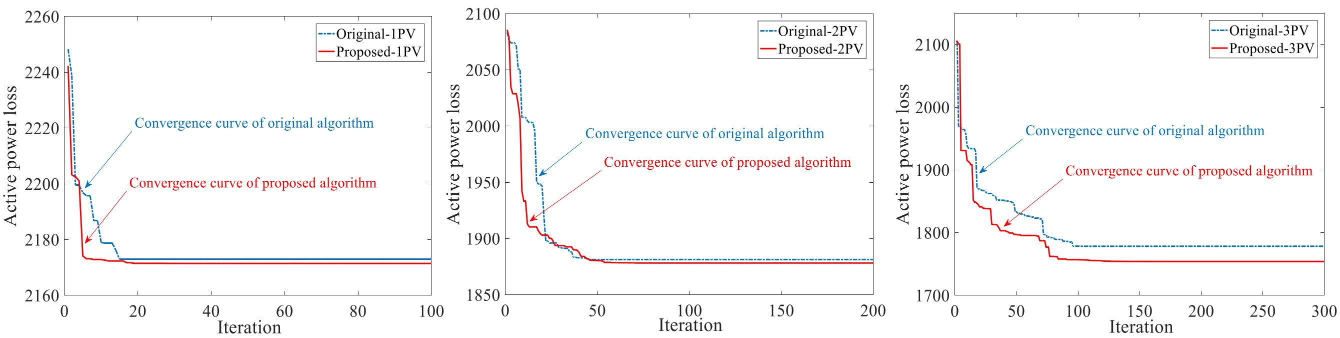

Fig. 9. Convergence curves of practical OAO problems with PV access

TABLE V
CG ALLOCATION SCHEMES ON DN WITH PRACTICAL LOADS

Algorithm	Node	Capacity/OPF	Node	Capacity/OPF	Node	Capacity/OPF	*DAEL* (KWh)
N_{CG}=1							
Original	6	2030.6/0.8311					1068.6086
Proposed	6	2049.0/0.8238					1067.6517
N_{CG}=2							
Original	11	677.5/0.8539	30	1061.1/0.8008			489.7878
Proposed	11	660.7/0.8836	30	1000.8/0.8000			470.7962
N_{CG}=3							
Original	13	654.2/0.8816	24	748.4/0.8721	30	900.5/0.8000	217.5995
Proposed	14	597.1/0.8830	24	845.1/0.8838	30	932.6/0.8000	213.0136

It should be noted that PV performs worse than CG in reducing the DAEL goal when connecting the same number of distributed generations. This is because the power generation of PV is extremely dependent on sunlight exposure, which can reduce or even stop in bad weather, affecting the stability of power supply. However, it cannot be ignored that PV converts light energy into electrical energy without consuming fossil fuels. It means that PV has no emission of greenhouse gases during the power generation process, which is environment-tally friendly. Therefore, it is very valuable to carry out the in-depth study on the integration of PV into DNs. And this paper also provides a good example for the application of PV in actual distribution system optimizations.

3) WT access

In addition to PV, this paper also studies the application of WT in OAO research and the hourly power output of WT is shown in Fig. 5. The convergence curves with different numbers of WTs obtained by BSOA and ISOAE are shown in Fig. 10. Table VII gives the WT allocation schemes including specific position, capacity and power factor which realize the minimum DAEL. In more detail, BSOA and ISOAE respectively reduce the DAEL to 562.8152 KWh and 543.9717 KWh when three WTS are connected. Similar to PV, WT is also a sustainable and environmental-friendly energy. As shown in Tables VI and VII, the DAEL reduced by WT is significantly better than the one reduced by PV when the same number of DGs are accessed. It demonstrates that WT has more competitive advantages than PV in solving OAO problems. The hourly power output curves of PV and WT shown in Fig. 5 also indicate that the power output of WT is more stable, and wind power can generate electricity 24/7 in areas with abundant wind resources. Therefore, WT has an undeniable potential advantage in the complex configuration optimization problems of distribution systems.

V. Conclusion

In order to obtain high-quality DG allocation schemes of OAO problems and realize better operation of distribution networks, an innovative ISOAE is proposed in this paper. The presented ISOAE has achieved better population diversity and superior local exploration ability than original BSOA based on the re-update operation and elite reserve population. The advantages of ISOAE compared to BSOA have been verified by multiple OAO experiments on both standard distribution network and the distribution network with practical load variation.

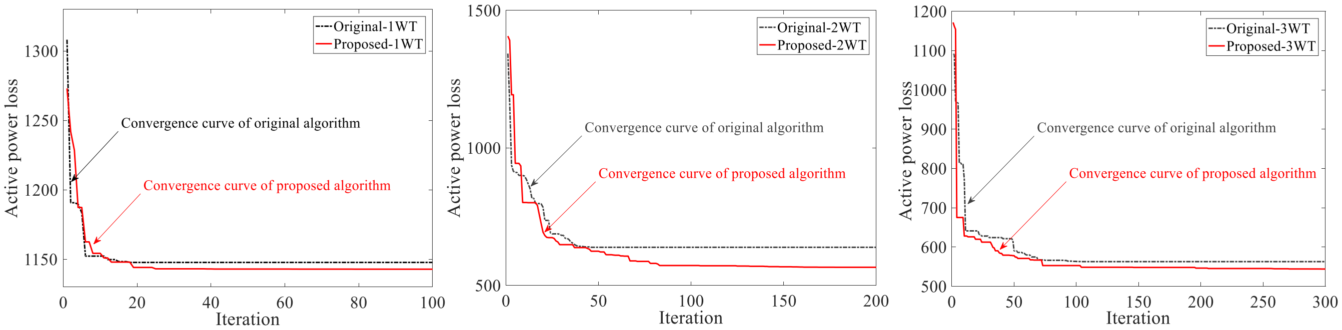

Fig. 10. Convergence curves of practical OAO problems with WT access

TABLE VI
PV Allocation Schemes on DN with Practical Loads

Algorithm	Node	Capacity/OPF	Node	Capacity/OPF	Node	Capacity/OPF	*DAEL* (KWh)
N_{PV}=1							
Original	6	3274.0/0.8250					2172.9585
Proposed	6	3144.5/0.8238					2171.4538
N_{PV}=2							
Original	13	1008.1/0.9003	30	1640.1/0.8044			1881.3639
Proposed	13	1018.3/0.8834	30	1539.6/0.8000			1878.2912
N_{PV}=3							
Original	14	865.7/0.8968	24	1038.8/0.8101	30	1201.8/0.8000	1778.3426
Proposed	14	920.3/0.8825	24	1290.5/0.8841	30	1436.3/0.8000	1754.0288

TABLE VII
WT Allocation Schemes on DN with Practical Loads

Algorithm	Node	Capacity/OPF	Node	Capacity/OPF	Node	Capacity/OPF	*DAEL* (KWh)
N_{WT}=1							
Original	30	3096.2/0.8064					1147.7134
Proposed	30	3305.2/0.8235					1142.8350
N_{WT}=2							
Original	13	1059.6/0.8045	30	2592.9/0.8666			638.4635
Proposed	14	1516.2/0.9161	30	2161.0/0.8013			565.7955
N_{WT}=3							
Original	14	1424.4/0.9148	17	223.3/0.8698	30	2027.8/0.8007	562.8152
Proposed	8	781.1/0.8520	15	1122.5/0.9236	30	1773.9/0.8000	543.9717

When solving the OAO problems on the standard DN with constant loads, ISOAE obtains more preferable DG allocation schemes with less active power loss, which surpasses BSOA and various existing algorithms. In the OAO cases which aim to reduce the daily active energy loss on the distribution system with actual loads, the applications of traditional CG and two renewable distributed generations are discussed. Simulation experiments demonstrate that ISOAE obtains more desirable allocation schemes with smaller DEAL than BSOA when accessing three different types of DGs. Compared with traditional CG, WT and PV as two representative renewable DGs have significant superiority, as they can reduce the dependence on fossil fuels and avoid environmental pollution. Moreover, WT with abundant resources and more stable power output has wider application prospects than PV in the actual OAO research.

The ISOAE proposed in this paper greatly reduces the power loss of DNs and achieves the more ideal node voltage profiles by rationally allocating the position, capacity and power factor of DGs. In conclusion, the suggested ISOAE provides an innovative technology that can effectively improve the flexibility of distribution systems and build the sustainable power grids.

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