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• LETTER •

Special Focus on Pigeon-Inspired Optimization

Dynamic economic emission dispatch based on multi-objective pigeon-inspired optimization with double disturbance

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Dear editor,
Recently, dynamic economic dispatch (DED) has attracted much attention in power system optimal operation [1, 2], because it considers the interplay between the different dispatching periods based on ramp rate limits of the generator units. To reduce emissions during the process of power generation, an extended model of DED, namely dynamic economic emission dispatch (DEED) [3, 4], has been proposed. It can be used to minimize both the fuel cost and emission release by scheduling the output of each generator during every dispatching period. Thus, in comparison with the static model, DEED is more practical and more in line with the actual short-term dispatching requirements.

Since DEED is a high dimensional, strongly coupled, nonlinear, non-convex, and constrained multi-objective optimization problem (MOP), it is difficult to be solved. Conventionally, the multi-objective DEED is normally converted into a single-objective optimization problem (SOP) [5] but it is hard to obtain more than one optimal solutions in a single run. Thus the whole set of Pareto optimal solutions cannot be provided to the decision makers. Recently, DEED problem has been formulated as a true MOP and few multi-objective evolutionary algorithms [6] have been modified to solve it.

Pigeon-inspired optimization (PIO) algorithm is a novel bio-inspired computation algorithm proposed by Duan [7] and has shown superior performance in some SOPs [8]. However, few studies have focused on the utilization of PIO in solving MOP. The basic multi-objective pigeon-inspired optimization (MPIO) was proposed by Qiu and Duan [9], which was based on Pareto sorting scheme and a consolidation operator. However, MPIO may show premature convergence while solving some complex MOP and could also not lead to true global optimal solutions.

This study aims to propose an improved MPIO with double disturbance (IMPIO-DD), i.e., adjacent disturbances (ADs) and small probability mutation (SPM). ADs and SPM operators were introduced to prevent premature convergence and enhance the diversity of the population. To the best of our knowledge, PIO was first used in DEED. Experimental results show that the proposed IMPIO-DD can solve the DEED problem effectively and efficiently.

Problem formulation. DEED problem can be formulated as a nonlinear constrained MOP, whose

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mathematical model can be expressed as follows:

$$\begin{cases} \min\ [f_1(P), f_2(P)], \\ \text{s.t.}\ \ g_i(P) = 0,\ i = 1, 2, \ldots, p, \\ \qquad h_j(P) \leqslant 0,\ j = 1, 2, \ldots, q, \end{cases} \tag{1}$$

where P is the output of all the generators over the entire dispatching periods and p and q are the number of equality and inequality constraints, respectively. For the multi-objective DEED problem, the two conflicting objectives cost (f_1) and emission (f_2) need to be minimized simultaneously subject to all equality and inequality constraints. The objectives and constraints employed in the present work are described as follows.

(1) Fuel cost. With the consideration of the valve point effect of the generators, the fuel cost function of each generator can be formulated as a sum of a quadratic function and a sinusoidal function. Therefore, the total fuel cost of the N units during all the dispatching periods can be expressed as follows:

$$\begin{aligned} f_1 = \sum_{t=1}^{T}\sum_{i=1}^{N}\{&a_i + b_i P_{it} + c_i P_{it}^2 \\ &+ |d_i \sin[e_i(P_i^{\min} - P_{it})]|\}, \end{aligned} \tag{2}$$

where T is the number of the dispatching periods, a_i, b_i, c_i, d_i and e_i are the cost coefficients of the ith generator and P_{it} is the output power of the ith generator during the tth period. The minimum output of the ith generator is defined as $P_i^{\min}$.

(2) Emission. The total emission of the atmospheric pollutants caused by all the fossil-fueled thermal units, such as CO_2, SO_x and NO_x, can be expressed as

$$f_2 = \sum_{t=1}^{T}\sum_{i=1}^{N}[\alpha_i + \beta_i P_{it} + \gamma_i (P_{it})^2 + \eta_i \exp(\delta_i P_{it})], \tag{3}$$

where α_i, β_i, γ_i, η_i, and δ_i are the emission coefficients of the ith generator.

(3) Power balance constraints.

$$\sum_{i=1}^{N} P_{it} = P_{Dt} + P_{Lt}, \quad t \in T \tag{4}$$

are the equality constraints of the multi-objective DEED problem where P_{Dt} and P_{Lt} are the power demand and power loss of the tth period, respectively. And based on the Kron's loss formula, the value of P_{Lt} can be calculated by

$$P_{Lt} = \sum_{i=1}^{N}\sum_{j=1}^{N} P_{it} B_{ij} P_{jt} + \sum_{i=1}^{N} P_{it} B_{i0} + B_{00},\ t \in T, \tag{5}$$

where B_{ij}, B_{i0} and B_{00} are the transmission network power loss B coefficients. B_{ij} is the ijth element of the loss coefficient square matrix, B_{i0} is the ith element of the loss coefficient vector, and B_{00} is the loss coefficient constant.

(4) Power operating limits.

$$P_i^{\min} \leqslant P_{it} \leqslant P_i^{\max}, \quad i \in N,\ t \in T, \tag{6}$$

where $P_i^{\min}$ and $P_i^{\max}$ represent the minimum and maximum power output of the ith generator, respectively.

(5) Ramp rate limits.

$$\begin{cases} P_{it} - P_{i(t-1)} \leqslant \mathrm{UR}_i \cdot \Delta t, \\ P_{i(t-1)} - P_{it} \leqslant \mathrm{DR}_i \cdot \Delta t, \end{cases} \quad i \in N,\ t \in T, \tag{7}$$

where UR_i and DR_i refer to the ramp up and down rate limits of the ith generator, respectively, and Δt is the time length of each dispatching period.

IMPIO-DD. An overview of the basic MPIO can be found in Appendix A. Lack of exploitation in the local region makes MPIO prone to premature convergence. Resultantly, it may converge to the local Pareto optimal front (POF) rather than the global POF. Therefore, an improved MPIO with a double disturbance that includes two key strategies is proposed.

(1) Adjacent disturbances (ADs). ADs can be regarded as a social learning factor which can help the algorithm to jump out of the local POF. Therefore, the population in IMPIO-DD can keep their exploration ability and move to the proper region. The updating formula of the velocity and the position in IMPIO-DD with the ADs can be expressed as follows:

$$\begin{aligned} \mathrm{AD} &= \mathrm{rand} \cdot (\boldsymbol{x}_{\mathrm{pbest\_}i} - \boldsymbol{x}_i(t-1)), \\ V_i(t) &= V_i(t-1) \cdot \mathrm{e}^{-R \times t} \\ &\quad + \mathrm{tr} \cdot (1 - \mathrm{lg}_{gm}^{t}) \cdot [\mathrm{AD} + \mathrm{MC}] \\ &\quad + \mathrm{tr} \cdot \mathrm{lg}_{gm}^{t} \cdot \mathrm{LM}, \\ \boldsymbol{x}_i(t) &= \boldsymbol{x}_i(t-1) + V_i(t), \end{aligned} \tag{8}$$

where AD indicates the ADs operator comprising of the personal best position $\boldsymbol{x}_{\mathrm{pbest\_}i}$ of the pigeon i in the tth iteration. The update method for $\boldsymbol{x}_{\mathrm{pbest}}$ is shown in Appendix B, whereas explanations for other variables can be found in Appendix A.2.

(2) Small probability mutation (SPM). SPM is introduced after the position update by (8) to increase the population diversity and to enhance the global search ability. Random disturbance generated by SPM can be expressed as follows:

$$\boldsymbol{x}_i = \begin{cases} \boldsymbol{x}_i + \mathrm{random}(r, -r), & \text{if rand} \leqslant p_m, \\ \boldsymbol{x}_i, & \text{otherwise}, \end{cases} \tag{9}$$

where $\boldsymbol{x}_i$ is disturbed within a circular region having a radius r with a small probability p_m.

Table 1 Results obtained by IMPIO-DD and MPIO for all the three cases

Method	Objective	Case1		Case2		Case3	
		Cost ($)	Emission (lb)	Cost ($)	Emission (lb)	Cost($)	Emission (lb)
IMPIO-DD	Best cost	**25549**	6.9328	**110550**	114.0744	**119780**	140.4679
	Best emission	26839	**5.6976**	123720	**68.4313**	137240	**92.2827**
	Best compromise	25880	5.9720	116710	82.1513	128580	101.3510
MPIO	Best cost	**26027**	6.2208	**116220**	88.1546	**127300**	113.2912
	Best emission	26036	**6.2108**	117440	**83.4975**	127850	**111.0852**
	Best compromise	26030	6.2170	116600	86.5584	127550	112.1846

The implementation details of IMPIO-DD including population initialization and algorithm flow are shown in Appendix C.

Experimental studies. Three cases of two typical test systems (i.e., IEEE 30-bus, 6-unit system and 118-bus, 14-unit system) were studied. And a scheduling cycle of 24 h with 1-h interval was considered. Detailed case description and experimental settings are shown in Appendix D.1. As shown in Table 1, for all the three cases studied, the proposed IMPIO-DD has a better performance than the basic MPIO. Moreover, the range between the extreme values of each objective in IMPIO-DD is wider than MPIO. This shows that POF obtained by IMPIO-DD has a wider spread in comparison with the one obtained using MPIO which is important for decision making in DEED. Meanwhile, the best compromise solutions obtained by IMPIO-DD are better than those of MPIO. Comparison between the proposed algorithm and other existing methods is shown in Appendix D.2.

Conclusion. Herein, we proposed an IMPIO-DD algorithm to solve the complex multi-objective DEED problem. ADs and SPM were introduced to prevent premature convergence and to enhance population diversity. Results show that IMPIO-DD outperforms MPIO significantly and, for all the three DEED cases, it has a better or the same performance in comparison with existing algorithms.

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Supporting information Appendixes A–D. The supporting information is available online at info.scichina.com and link.springer.com. The supporting materials are published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.

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