

# Dynamic Economic Dispatch in Thermal-Wind-Small Hydropower Generation System

Guangbiao Liu<sup>1,2</sup>, Jianzhong Zhou<sup>1,2,\*</sup>, Xiaogang Xiao<sup>3</sup>, Li Mo<sup>1,2</sup>, Yang Yuqi<sup>1,2</sup>, and Lu Chengwei<sup>1,2</sup>

<sup>1</sup> School of Hydropower and Information Engineering, Huazhong University of Science and Technology, Wuhan 430074, China

<sup>2</sup> Hubei Key Laboratory of Digital Valley Science and Technology, Wuhan 430074, China

<sup>3</sup> Central China Power Grid Company, Wuhan, Hubei 430077, China

**Abstract.** With the large-scale wind power integration, the uncertainty of wind power poses a great threat to the safe and stable operation of the system. This paper proposes dynamic economic dispatch problem formulation in thermal power system incorporating stochastic wind and small-hydro (run-in-river) power, called thermal-wind-small hydropower system (TWSHS). Weibull and Gumbel probability density functions are used to calculate available wind and small-hydro power respectively. An improved differential evolution algorithm based on gradient descent information (DE-GD) is proposed to solve the dynamic economic dispatch (DED) problem considering uncertainty of wind power and small-hydro power, as well as complicated constraints in TWSHS. Based on the traditional differential evolution algorithm, the gradient information of the objective function is introduced after the mutation process to enrich the diversity of the population, thus increasing the possibility of convergence to the global optimization. Generation scheduling is simulated on a TWSHS with the proposed approach. Simulation results verify feasibility and effectiveness of the proposed method while considering various complex constraints in the thermal-wind-small hydropower system.

## 1 Introduction

Classical economic power dispatch problem is formulated with only thermal generators. But importance of reduction in emission is paramount from environmental sustainability perspective and hence penetration of more and more renewable sources into the electrical grid is encouraged. Small hydropower is concentrated in southern China, and the cumulative grid-connected capacity of wind power is also increasing year by year. In 2017, the cumulative installed capacity of Yunnan and Guizhou was 8190MW and 3690MW respectively. Compared with 2016, it increased by 123.9% and 11.1% respectively. Therefore, it is necessary to consider the connection between small hydropower and wind power in the economic dispatch of power system.

Dynamic economic dispatch (DED) is a method to schedule the online generator outputs with the predicted load demands over a certain period of time so as to operate an electric power system most economically [1]. It is a dynamic optimization problem taking into account the constraints imposed on system operation by generator ramping rate limits. The DED is not only the most accurate formulation of the economic dispatch problem but also the most difficult to solve because of its large dimensionality.

In recent years, several literature studied DED problem applying evolutionary algorithms. Chaotic bat

algorithm (CBA) was implemented to perform the optimization in Ref.[2]. Ref.[3] proposed a new hybrid grey wolf optimizer (HWGO) with addition of mutation and crossover operators into grey wolf optimizer. In Ref.[4], multi-fuel option and valve-point loading effect of stream turbine generators were taken into account. Delshad [5] performed the study using backtracking search algorithm (BSA) with added complexity of generator prohibited operating zone (POZ) to Ref.[4]. Based on the previous studies, this paper proposes dynamic economic dispatch problem formulation in thermal power system incorporating stochastic wind and small-hydro (run-in-river) power, called thermal-wind-small hydropower system (TWSHS). Weibull and Gumbel probability density functions are used to calculate available wind and small-hydro power respectively. An improved differential evolution algorithm based on gradient information (DE-GI) is proposed to solve the dynamic economic dispatch (DED) problem considering uncertainty of wind power and small-hydro power, as well as complicated constraints in TWSHS. Generation scheduling is simulated on a TWSHS with the proposed approach. Simulation results verify feasibility and effectiveness of the proposed method while considering various complex constraints in the thermal-wind-small hydropower system.

## 2 Problem formulation

\*Corresponding author: [jz.zhou@mail.hust.edu.cn](mailto:jz.zhou@mail.hust.edu.cn)

The objective of DED problem is to realize minimum of the total economic cost, while considering the stochastic availability of wind power and small hydropower with equality and inequality constraints.

## 2.1 Objective function

The fuel cost function of thermal units includes valve point loading effects and can be formulated as the follows:

$$\begin{cases} \min C = \sum_{t=1}^T \sum_{i=1}^N C_{it}(P_{it}) \\ C_{it}(P_{it}) = a_i P_{it}^2 + b_i P_{it} + c_i + |d_i \sin(e_i (P_{i\min} - P_{it}))| \end{cases} \quad (1)$$

Where  $C$  is the total operating cost over the whole dispatch period of  $n$  thermal units.  $T$  is the length of dispatch period.  $C_{it}(P_{it})$  is the generation production cost of  $i$ -th unit in terms of real power output  $P_i$  at time  $t$ .  $a_i, b_i, c_i$  are the cost coefficients of  $i$ -th unit,  $d_i, e_i$  are the coefficients of the valve point effects concerned. Minimum power of the  $i$ -th thermal unit when in operation is  $P_{i\min}$ .

## 2.2 Constraints

### 1) Active power balance

In the TWSHS, in addition to thermal power units, the output power of wind turbines and small hydropower plants must be considered. So the active power balance can be expressed as Eq.(2).

$$\sum_{i=1}^{N_t} P_{it}^{TH} + \sum_{i=1}^{N_w} P_{it}^W + \sum_{i=1}^{N_H} P_{it}^H = P_{LDt} \quad (2)$$

Where  $P_{it}^{TH}, P_{it}^W, P_{it}^H$  are the real power of  $i$ -th thermal unit, windfarm and small hydropower plant at time  $t$  respectively.  $P_{LDt}$  is the load demand in the TWSHS during  $t$ -th interval.  $N_t$  is the number of generators,  $N_w$  is the number of site of windfarm,  $N_H$  is the number of the small hydropower plants.

### 2) Power output limits

$$\begin{cases} P_{i\min}^{TH} \leq P_{it}^{TH} \leq P_{i\max}^{TH} \\ 0 \leq P_{it}^W \leq P_{ir}^W \\ P_{i\min}^H \leq P_{it}^H \leq P_{i\max}^H \end{cases} \quad t \in T \quad (3)$$

Where  $P_{i\min}^{TH}, P_{i\max}^{TH}$  are the minimum and maximum output of  $i$ -th thermal unit respectively.  $P_{ir}^W$  is rated power of  $i$ -th windfarm.  $P_{i\min}^H, P_{i\max}^H$  are the minimum and maximum output of  $i$ -th small hydropower plant, respectively.

### 3) Generator unit ramp rate limits

$$\begin{cases} P_{it}^{TH} - P_{it-1}^{TH} \leq UR_i \\ P_{it-1}^{TH} - P_{it}^{TH} \leq DR_i \end{cases} \quad t \in T, i \in N_t \quad (4)$$

Where  $UR_i, DR_i$  are the up-ramp and down-ramp limits of the  $i$ -th thermal unit, respectively.

## 3 SOLUTION METHOD

### 3.1 Differential Evolution Algorithm Review

Differential evolution algorithm is used to solve such optimization problems, which can be divided into initialization, mutation, crossover and selection.

#### 1) Initialization

$$\{X_i^0 | x_{i,j}^L \leq x_{i,j}^0 \leq x_{i,j}^U; \quad i = 1, 2, 3, \dots, NP; j = 1, 2, 3, \dots, D\} \quad (5)$$

Where  $X_i^0$  is the  $i$ th individual of the initial population,  $D$  denotes the dimension of the problem,  $NP$  is the size of population.

$$x_{i,j}^0 = x_{i,j}^L + rand(0,1)(x_{i,j}^U - x_{i,j}^L) \quad (6)$$

Where  $x_{i,j}^L$  and  $x_{i,j}^U$  are the  $j$ th dimension lower and upper limits, respectively.  $rand(0,1)$  is a uniformly distributed random number,  $rand(0,1) \sim U(0,1)$ .

#### 2) Mutation

DE algorithm achieves individual mutation through differential strategy. The common differential strategy is to randomly select two different individuals in the population, and then scale the vector difference and synthesize the vectors with the individuals to be mutated.

$$V_i^{g+1} = X_{r_1}^g + F(X_{r_2}^g - X_{r_3}^g) \quad (7)$$

Where  $r_1, r_2$  and  $r_3$  are three random number of interval  $[1, NP]$ .  $F \in [0, 2]$  is called the differential weight.  $g$  represents the  $g$ th generation.

#### 3) Crossover

The purpose of crossover is to randomly select individuals, because differential evolution is also a random algorithm, and the method of crossover is as follow.

$$U_{i,j}^{g+1} = \begin{cases} V_{i,j}^{g+1} & \text{if } rand(0,1) \leq CR \\ x_{i,j}^g & \text{otherwise} \end{cases} \quad (8)$$

Where the parameter  $CR \in [0, 1]$  is called the crossover probability.

#### 4) Selection

In DE, greedy choice strategy is adopted, that is to choose the better individual as the new individual.

$$X_i^{g+1} = \begin{cases} U_i^{g+1} & \text{if } f(U_i^{g+1}) \leq f(X_i^g) \\ X_i^g & \text{otherwise} \end{cases} \quad (9)$$

Where  $X_i^{g+1}$  denotes the new  $i$ th individual of the  $(g+1)$ th generation.

### 3.2 Gradient descent

Gradient descent is based on the observation that if the multi-variable function  $F(x)$  is defined and differentiable in a neighbourhood of a point  $x_n$ ,  $x$  is a vector, then  $F(x)$  decreases fastest if one goes from  $x_n$

in the direction of the negative gradient if  $F(x)$  at  $x_n$ ,  $-\nabla F(x_n)$ . It follows that.

$$x_{n+1} = x_n - \gamma \nabla F(x_n) \quad (10)$$

Where  $\gamma$  is constant parameter and small enough. Then  $F(x_n) \geq F(x_{n+1})$ . In other words,  $\gamma \nabla F(x_n)$  is subtracted from  $x_n$  to move against the gradient, toward the minimum.

### 3.3 Calculation of stochastic power of wind and small hydropower

#### 1) Wind power probabilities

The Weibull probability density function (PDF) method is predominantly used to describe the stochastic characteristic of wind speed. Its PDF is given by Eq.(11) as follow [7].

$$f_v(v) = \left(\frac{\beta}{\alpha}\right) \left(\frac{v}{\alpha}\right)^{(\beta-1)} e^{-(v/\alpha)^\beta} \quad v > 0 \quad (11)$$

Where  $\alpha$  and  $\beta$  are the scale and shape parameters for PDF, respectively.  $v$  is the current wind speed.

Wind power output is determined by wind speed, and the relationship between power and wind speed can be expressed as Eq.(12).

$$P^w(v) = \begin{cases} 0 & v < v_{in} \text{ or } v > v_{out} \\ P_r^w \left( \frac{v - v_{in}}{v_{out} - v_{in}} \right)^3 & v_{in} \leq v \leq v_{out} \\ P_r^w & v_r < v \leq v_{out} \end{cases} \quad (12)$$

Where  $v_{in}$ ,  $v_{out}$  and  $v_r$  are the cut-in, cut-out and rated wind speed, respectively.

#### 1) Small hydropower probabilities

Small hydropower is often a runoff type power station, so it has no regulating ability, and its output is mainly affected by inflow. The relationship between power and inflow rate can be described as Eq.(13).

$$P^H(Q) = \eta \rho g Q H \quad (13)$$

Where  $\eta$ ,  $\rho$  and  $g$  are the power generation efficiency of plant, water density and acceleration gravity, respectively.  $H$  is the power generation head.

In this paper, the Gumbel distribution is used to describe the runoff randomness of small hydropower stations. The probability of inflow rate  $Q$  following Gumbel distribution with parameter  $\lambda$  and scale parameter  $\gamma$  is expressed as follow [8].

$$f^w(Q) = \frac{1}{\gamma} e^{-\frac{Q-\lambda}{\gamma}} e^{-e^{-\frac{Q-\lambda}{\gamma}}} \quad (14)$$

## 4 The proposed approach

As DE algorithm is a stochastic optimization algorithm, the diversity of population determines the effect of the algorithm in the process of evolution, so this paper introduces gradient descent method to enrich the

diversity of population based on traditional DE. The main idea is to make a gradient descent of the individual population after the mutation process to get a new population, and use the population to cross with the population produced by the mutation process in the crossover process.

### 4.1 Frame of the proposed approach

The algorithm flow chart is shown in the following figure Fig.1.

#### 4.1 Structure of individuals

In the DED problem with renewable resources, the output power of thermal units,  $P_{it}^{TH}$ , is selected as decision variables. The array of the decision variable can be represented as follow.

$$Ind = \begin{bmatrix} P_{1,1} & P_{2,1} & \dots & P_{N',1} \\ P_{1,2} & P_{2,2} & \dots & P_{N',2} \\ \vdots & \vdots & \ddots & \vdots \\ P_{1,T} & P_{2,T} & \dots & P_{N',T} \end{bmatrix} \quad (15)$$

#### 4.2 Initialization of population

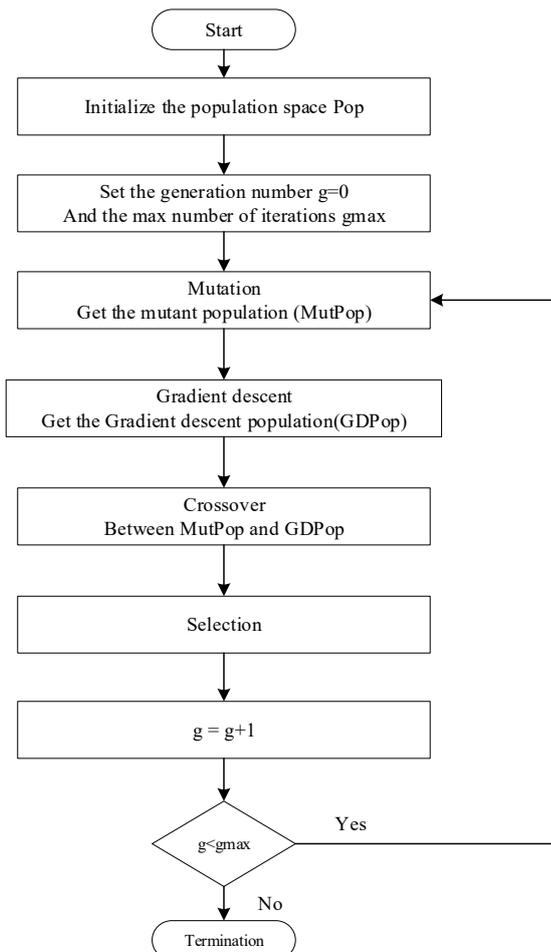
The initial population Pop is generated by creating the size of population,  $NP$ , solutions randomly within the feasible ranges of constraints (3) and (4).

$$P_{it}^{TH} = P_{i \min}^{TH} + rand(0,1)(P_{i \max}^{TH} - P_{i \min}^{TH}) \quad i = 1, 2, \dots, NP, t = 1, 2, \dots, T \quad (16)$$

#### 4.3 Constraint handling

Considering the constraint (4), the feasible region of decision variables should be compressed, the specific implementation is shown as Eq.(17).

$$\begin{cases} \begin{cases} P_{it}^{\min} = P_{i \min}^{TH} \\ P_{it}^{\max} = P_{i \max}^{TH} \end{cases} & t = 0 \\ \begin{cases} P_{it}^{\min} = \max(P_{i \min}^{TH}, P_{it-1}^{TH} - DR_i) \\ P_{it}^{\max} = \min(P_{i \max}^{TH}, P_{it-1}^{TH} + UR_i) \end{cases} & 0 < t < T \end{cases} \quad (17)$$



**Figure 1.**the flow chart of DE-GD

In view of load balance constraints, the first thermal power unit is regarded as compensation unit and the other units as decision control unit, so the decision variable vector is changed to:

$$Ind = \begin{bmatrix} P_{2,1} & P_{3,1} & \cdots & P_{N',1} \\ P_{2,2} & P_{3,2} & \cdots & P_{N',2} \\ \vdots & \vdots & \ddots & \vdots \\ P_{2,T} & P_{3,T} & \cdots & P_{N',T} \end{bmatrix} \quad (18)$$

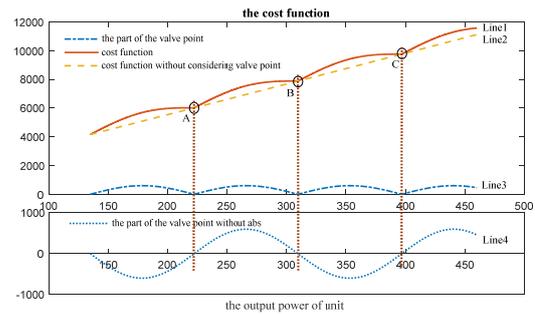
And the power of first unit can be calculated by Eq.(19)

$$P_{it}^{TH} = P_{LDt} - \sum_{i=2}^{N'} P_{it}^{TH} \quad (19)$$

#### 4.4 Gradient processing method of objection

As shown in Fig.2, Line 1 is the cost function with valve point effect, Line 2 is the cost function without considering valve point effect, and Line 3 is the cost component due to the valve point effect alone, Line 3 is based on Line 4 to obtain absolutely worthwhile curves. And Line 1 equals arithmetic sum of Line 2 and Line 3. Point A, B, and C are the non-differentiable points.

Because the objective function takes into account the valve point effect of thermal power units, the objective function appears non-differentiable points. Therefore, in this paper, these non-differentiable points are treated separately when the gradient is calculated.



**Figure 2.** the cost function of DED

In this paper, when calculating the gradient of cost function, the gradient of Line 2 at the point is used as the gradient information in the evolution process at the point A, B and C, so the gradient information is shown as follows.

$$\frac{\delta C}{\delta P_{it}} = \begin{cases} 2a_i P_{it} + b_i + (-d_i e_i \times \cos(e_i (P_{i\min} - P_{it}))) & d_i \sin(e_i (P_{i\min} - P_{it})) \geq 0 \\ 2a_i P_{it} + b_i - (-d_i e_i \times \cos(e_i (P_{i\min} - P_{it}))) & d_i \sin(e_i (P_{i\min} - P_{it})) < 0 \\ 2a_i P_{it} + b_i & d_i \sin(e_i (P_{i\min} - P_{it})) = 0 \end{cases} \quad (20)$$

So this paper uses gradient descent to generate new individuals as shown below.

$$P_{it}^{g+1} = P_{it}^g + \gamma \left( -\frac{\delta C}{\delta P_{it}^g} \right) \quad i = 1, 2, \dots, N', t = 1, 2, \dots, T \quad (21)$$

## 5 Case Study

In this section, the dispatching period is one day, the length of the period is 24 hours. The case includes ten thermal units, two sites of windfarm and one small hydropower plant. The load demand, the output constraints of thermal power units and the cost coefficient are selected as Ref.[1], and the parameters of the probability density function of wind power and small hydropower output are referred to Ref.[6].

### 5.1 Parameters setting

The parameters of DE-GD algorithm are set as follow:  $NP=100$ , the maximum number of iterations  $g_{\max}=60000$ , the differential weight  $F=0.5$  and the crossover probability  $CR=0.8$ . The learning rate of gradient descent method used in this paper is 0.001,  $\gamma=0.001$ .

### 5.2 Simulation results and analysis

#### 1) the results of DE and DE-GD

In the experiment, DE algorithm and DE-GD algorithm are used to solve the DED problem. The results are shown in Table 1. The best solution of DE-GD algorithm is shown in Appendix.

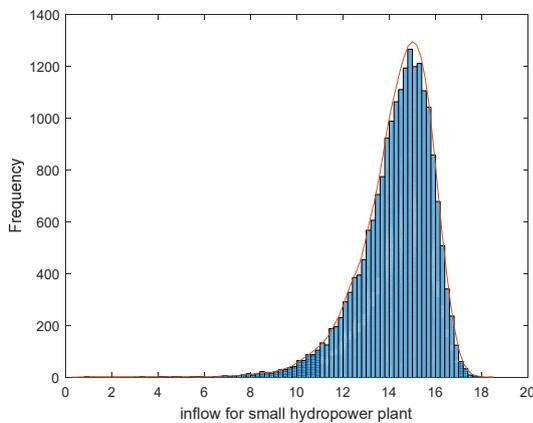
It can be seen from Table 1, the cost of DED problem with DE-GD algorithm has the lower value than the DE algorithm, the difference between the two results reaches 1201.1\$.

**Table 1.** The cost of DED problem with DE and DE-GD

Inflow Distribution	Weed speed distribution	Algorithm	Cost(\$)
Fig.3	Fig.5	DE-GD	993283.34
Fig.3	Fig.5	DE	994484.44

2) the results of different renewable sources distribution

In order to verify that the algorithm is applicable to different inflow of small hydropower plant distribution and different wind power output distribution, the distribution of wind power and inflow is changed respectively, and the validity of the algorithm is verified by experiment. Figure 3 and Figure 4 are different inflow distribution, and Figure 5 and Figure 6 are different wind power distribution. The diagrams of these figures are obtained by 10000 times Monte Carlo scenarios with selected values of PDF parameters.

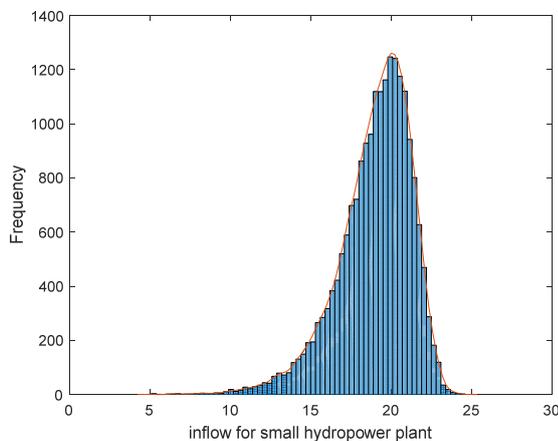


**Figure 3.** Inflow of small hydropower plant distribution for  $\lambda = 15, \gamma = 1.2$

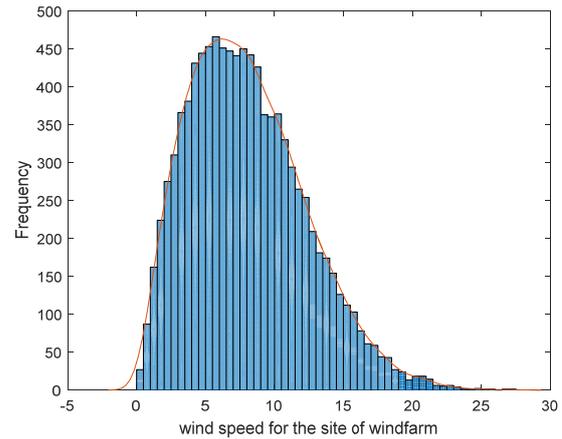
• *With the different inflow distribution*

With the different inflow distribution and the same wind speed distribution, the results of DED with the DE-GD algorithm are shown in Table 2.

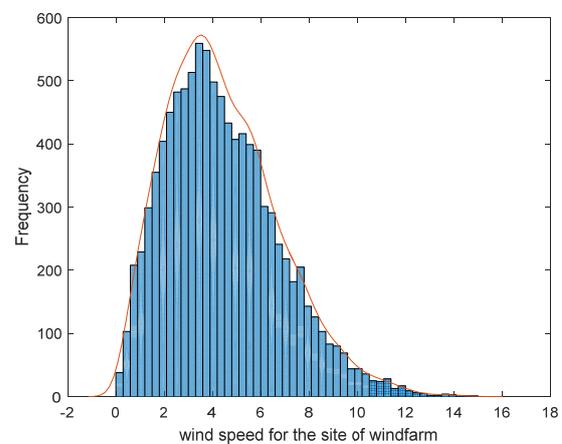
It can be seen from the Table 2 that the results of DE-GD algorithm are similar under different inflow distribution.



**Figure 4.** Inflow of small hydropower plant distribution for  $\lambda = 20, \gamma = 1.8$



**Figure 5.** Wind speed (m/s) distribution for  $\alpha = 9, \beta = 2$



**Figure 6.** Wind speed (m/s) distribution for  $\alpha = 5, \beta = 2$

**Table 2.** The cost of DED problem with different inflow distribution

Inflow Distribution	Weed speed distribution	Algorithm	Cost(\$)
Fig.3	Fig.5	DE-GD	993283.34
Fig.4	Fig.5	DE-GD	993497.65

• *With the different wind speed distribution*

With the different wind speed distribution and the same inflow distribution, the results of DED with the DE-GD algorithm are shown in Table 3.

It can be seen from the Table 3 that the results of DE-GD algorithm are similar under different wind speed distribution.

**Table 3.** The cost of DED problem with different wind speed distribution

Inflow Distribution	Weed speed distribution	Algorithm	Cost(\$)
Fig.3	Fig.5	DE-GD	993283.34
Fig.3	Fig.6	DE-GD	1017625.16

## 6 Conclusions

In this paper, based on the previous studies on DED, the gradient information and differential evolution algorithm are used to solve the DED problem, which combines wind power and small hydropower with strong

randomness. In the process of DE algorithm, gradient descent method is introduced to increase the number of new species, thus enriching the diversity of population. Aiming at the non-differentiable point of the cost function in DED problem, this paper adopts the piecewise gradient method to obtain the gradient of the objective function, and considers that the non-differentiable point of the objective function is just the local optimum. In order to prevent the algorithm from falling into the local optimum, the gradient of the trend information of the cost function is used at the non-differentiable point. At the same time, the method is compared with the traditional differential evolution, and the results show the effectiveness of the proposed method. Considering the randomness of small hydropower and wind power, the method proposed in this paper is used to solve the DED problem of small

hydropower and wind power with different distribution. The results show that the method is also effective for different renewable energy output scenarios.

### Acknowledgments

This work is supported by the National Key R&D Program of China (No.2016YFC0402205), the science and technology project of state grid corporation (No.SGHZ0000DKJS1800195), National Natural Science Foundation Project of China (NSFC) (No.51509095 , No. 51479075), the Fundamental Research Funds for the Central Universities(2017KFYXJJ192).

### Appendix

**Table A1** the best solution of the DED with DE-GD

U/P	1	2	3	4	5	6
Thermal.1	226.59	303.51	303.22	303.28	379.91	379.85
2	135.00	135.00	141.94	221.91	222.24	229.38
3	119.26	107.95	183.60	212.34	185.69	187.26
4	60.02	60.00	109.81	120.36	120.31	156.46
5	122.84	122.80	122.83	122.84	122.86	122.81
6	122.42	122.63	122.41	123.16	122.44	122.46
7	56.53	56.53	56.53	56.50	63.18	93.05
8	85.33	85.30	85.30	85.32	85.31	85.31
9	20.00	20.36	50.27	51.92	21.95	51.88
10	55.00	55.00	55.00	55.00	55.00	55.00
Wind1	14.89	18.93	11.87	25.08	48.98	70.92
Wind2	14.89	18.93	11.87	25.08	48.98	70.92
Small Hydro	3.24	3.05	3.35	3.20	3.15	2.72
U/P	7	8	9	10	11	12
Thermal.1	379.88	379.84	379.93	456.54	456.65	456.58
2	309.36	309.50	309.52	316.53	396.49	459.95
3	191.69	268.05	318.05	298.64	338.30	317.33
4	180.82	180.39	180.81	230.72	246.81	296.78
5	172.67	172.69	172.77	222.42	222.55	222.55
6	123.13	122.39	124.74	122.45	122.48	142.64
7	93.07	93.05	93.05	99.60	129.58	129.59
8	85.31	85.31	85.32	85.30	85.27	85.33
9	51.85	21.88	51.84	52.02	52.03	52.03
10	55.00	55.00	55.00	55.00	55.00	55.00
Wind.1	28.04	42.23	75.00	64.71	19.09	0.00
Wind.2	28.04	42.23	75.00	64.71	19.09	0.00
Small Hydro	3.16	3.44	2.97	3.35	2.67	2.23
U/P	13	14	15	16	17	18
Thermal.1	379.88	379.61	303.24	303.31	303.26	303.30
2	396.75	389.50	309.51	305.21	225.28	228.92
3	297.29	286.34	232.52	183.81	172.14	214.27
4	285.85	237.86	230.45	180.49	180.83	210.76
5	222.54	222.05	172.69	172.64	122.84	172.71

6	122.39	122.40	122.39	122.35	72.88	122.42
7	123.00	93.08	93.04	93.05	93.05	93.09
8	85.28	85.31	85.30	85.29	85.29	85.27
9	52.03	49.93	20.01	49.73	21.69	51.64
10	55.00	55.00	55.00	55.00	55.00	55.00
Wind1	24.45	0.00	75.00	0.00	72.38	43.79
Wind2	24.45	0.00	75.00	0.00	72.38	43.79
Small Hydro	3.09	2.93	1.85	3.12	2.99	3.03
U/P	19	20	21	22	23	24
Thermal.1	303.20	379.60	303.30	303.32	226.63	226.39
2	308.88	388.71	309.56	309.18	229.21	222.10
3	292.96	285.25	300.65	220.75	181.99	178.16
4	241.14	236.30	255.31	206.30	168.27	120.28
5	172.62	222.40	222.56	172.68	122.84	122.78
6	122.43	122.31	125.84	122.40	122.41	122.42
7	93.03	93.03	93.07	93.05	86.51	56.52
8	85.27	85.29	85.36	83.69	53.71	47.00
9	52.02	51.32	52.03	49.96	20.00	20.00
10	55.00	55.00	55.00	55.00	55.00	55.00
Wind1	23.61	75.00	59.35	4.44	31.23	5.17
Wind2	23.61	75.00	59.35	4.44	31.23	5.17
Small Hydro	2.24	2.79	2.62	2.78	2.98	2.99

## References

1. P Attaviriyannupap, IEEE TRANSACTIONS ON POWER SYSTEM, **22** (4), 77-77 (2007)
2. Adarsh BR, et al, International Conference on Control, Energy **96**, 666-75 (2016)
3. Jayabarathi T, Raghunathan T, et al. Energy **111**, 630-41 (2016)
4. Meng Anbo, Li Jinbei, et al, Energy **113**, 1147-61 (2016)
5. Modiri-Delshad M, Kaboli SHA, et al. Energy, **116**, 637-49 (2016)
6. PP Biswas, PN Suganthan, et al, Energy, (2018)
7. Biswas Partha P, Suganthan PN, et al. Energy Convers Manag, **148**, 1194-207 (2017)
8. Mujere Never. Int J Comput Sci Eng, **3**(7), 2774-8 (2011)