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Improved particle swarm optimization techniques to wind-thermal coordination

Min Lu* and Mi Zhao

State Key Laboratory of Power Transmission Equipment & System Security and New Technology, Chongqing, China

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ABSTRACT

There is strong randomness in wind power, and its output is not controllable. Large scale wind power grid-connection to dispatch system brings new uncertainty. This paper constructs the wind-thermal random optimal model based on improved PSO algorithm and achieves the coordination of power cost and pollution emissions of thermal power units. Aimed at drawback of basic PSO algorithm, the paper uses chaos optimization search process to speed up the search and convergence speed. This improved algorithm could improve the coordination between global and local searching ability and apt to search out global optimum quickly. Finally, multi-objective optimal scheduling is illustrated by using the thermal-10 node. The results show that the improved PSO arithmetic solution set uniform distribution, predict accuracy and qualified rate is out of the solution of the highest degree of coordination, get each time specific unit output of the plan, according to the calculation results make corresponding power generation plan, to access a fairly large wind power dispatch system has the actual reference value, so the proposed method is feasible and effective.

Key words: wind-thermal system; improved PSO; coordination; chaos

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NOMENCLATURE

d	Percentage of maximum unit capacity hour t	$P_i^{\max}(t)$ $P_i^{\min}(t)$	Maximum and minimum generation respectively of ith thermal unit
$P_{WT}^{*}(t)$	Total available wind generation at hour t	$P_{WT}(t)$	Total actual wind generation at hour t
$P_{i,r}^{\min}$	Lower generation limit of ith thermal unit	$P_{W,j}^{\max}$	Upper generation limit of jth wind unit
$DR_i^{\max}$	Maximum ramp-down rate and down reserve	DRW	Down spinning reserve requirement
$P_L(t)$	System load demand at hour t	$P_{W,j}^{*}(t)$	Available generation of jth wind unit at hour t
$DS_i^{\max}$	Maximum up reserve contribution of ith thermal uni t	SR_i	Startup ramp rate limit of ith thermal Unit
		STC_i	Startup cost of ith thermal unit
$DS_i(t)$	Down reserve contribution of ith thermal unit at hour t	$TDR(t)$	System ramping down capacity at hour t
T	Number of time intervals (hours)	$T_{OFF,i}$	Minimum down time of ith thermal unit

$t_{OFF,i}(t)$	Down period of ith thermal unit till time t	$t_{ON,i}(t)$	Up period of i[th] thermal unit at time t
$T_{ON,i}$	Minimum up time of i[th] thermal unit	$UR_i^{\max}$	Maximum ramp-up rate of i[th] thermal unit
$TUR(t)$	System ramping up capacity at hour t	$I_i(t)$	Schedule state of i[th] thermal unit for hour t
URW	Up spinning reserve requirement considering wind power generation.	$US_i^{\max}$	Maximum up reserve contribution of i[th] thermal unit
$US_i(t)$	Up reserve contribution of i[th] thermal unit at t	NT	Number of thermal units
USR_B	System up spinning reserve requirements not considering wind power generation	$P_i(t)$	Generation of i[th] thermal unit at hour t
F_T	Total operation cost during period T	$P_{i,r}^{\max}$	Upper generation limit of i[th] thermal unit
i, j	Index for thermal and wind units, respectively	NW	Number of wind units

INTRODUCTION

Electricity is a kind of extremely clean energy, but in the use of the energy have the negative effects on the environment [1-3]. At present, our country still with thermal power is given priority to, Thermal power units are more than 70% of capacity totally[4], in the future for a long time still can't change the condition, therefore, consider the clean energy and firepower unit united cooperation is a kind of practical needs. Energy saving power is the dispatch according to the energy saving, environmental protection, economy of the principles of power dispatch under the premise of reliable power supply. Priority to scheduling wind energy, water, biomass energy and other renewable power generation resources, then scheduling coal and power resources is a very important and necessary problem [5].

In the specific scheduling, press unit as pollutant emission or energy consumption level from low to high arrangement online, minimize resource consumption and pollution emission. Compared with the traditional dispatching, energy saving dispatching is more attention to energy conservation and environmental protection [6]; reduce the unit in the production of electric energy emphasis on pollutants; tend more to schedule the renewable energy units and large environmental fire unit efficiency. Thus, which saves energy, reduces the pollution of the environment, and realizes the sustainable development of the power industry [7-10].

The wind-thermal unit commitment solution methods reported in the literature include Simulated Annealing [8], Hybrid Dynamic Programming [11], and Fuzzy Mixed Integer Linear programming techniques [12]. This paper improves algorithm to the coordination global and local searching ability and is apt to search out global optimum quickly.

THE WIND-THERMAL POWER MATHEMATICAL MODEL

The objective function

(1) Economic Goals [13]

First consider the system of the unit cost of conventional fire power generation minimization (ignore the wind power generating cost)

$$mimize \quad F_T = \sum_{t=1}^{T}\sum_{i=1}^{NT}[I_i(t)\times F_i(P_i(t)) + I_i(t)\times(1-I_i(t-1)\times STC_i) \quad (1)$$

Where subject to following constraints:

1) System constraints

a) Power balance constraint (losses are neglected)

$$\sum_{i=1}^{NT} I_i(t)\times P_i(t) + P_{WT}(t) = P_L(t) \tag{2}$$

b) System up/down spinning reserve requirements

$$\sum_{i=1}^{NT} I_i(t)\times US_i(t) \ge USR_B + URW(P_{WT}(t)) \tag{3}$$

$$\sum_{i=1}^{NT} I_i(t)\times DS_i(t) \ge DRW(P_{WT}(t)) \tag{4}$$

c) Minimum/maximum thermal plant output constraints

$$P_L(t) - P_{WT}(t) \ge DRW(P_{WT}(t)) + \sum_{i=1}^{NT} I_i(t) \times P_{i,r}^{\min}(t) \tag{5}$$

$$\sum_{i=1}^{NT} I_i(t) \times P_i^{\max}(t) + P_{WT}(t) \ge P_L(t) + USR_B + URW(P_{WT}(t)) \tag{6}$$

2) Thermal generator constraints
a) Unit's maximum up/down reserve contribution constraints

$$US_i^{\max} = d \times P_{i,r}^{\max} \ and \ \ DS_i^{\max} = d \times P_{i,r}^{\max} \tag{7}$$

b) Unit's up/down reserve contribution constraints

$$US_i(t) = \min(US_i^{\max}, P_{i,r}^{\max} - P_i(t)) \tag{8}$$

$$DS_i(t) = \min(DS_i^{\max}, P_i(t) - P_{i,r}^{\min}) \tag{9}$$

c) Unit's ramping up/down capacity constraints

$$UR_i(t) = \min(UR_i^{\max}, P_{i,r}^{\max} - P_i(t)) \tag{10}$$

$$DR_i(t) = \min(DR_i^{\max}, P_i(t) - P_{i,r}^{\min}) \tag{11}$$

d) Unit generation limits

$$\begin{aligned} & P_i^{\min}(t) \times I_i(t) \le P_i(t) \le P_i^{\max}(t) \times I_i(t) \\ & \quad if \ \ I_i(t) = I_i(t-1) = 1 \\ & \ P_i^{\max}(t) = \min\{P_{i,r}^{\max}, P_i(t-1) + UR_i^{\max}\} \\ & \quad if \ \ I_i(t) = I_i(t-1) = 0 \\ & \qquad\qquad = \min\{P_{i,r}^{\max}, P_i(t-1) + SR_i\}, \end{aligned} \tag{12}$$

$$\begin{aligned} & if \ \ \ I_i(t) = I_i(t-1) = 1 \\ & P_i^{\min}(t) = \max\{P_{i,r}^{\min}, P_i(t-1) - DR_i^{\max}\}, \\ & if \ \ \ if \ \ I_i(t) = I_i(t-1) = 0 \\ & \qquad\quad = P_{i,r}^{\min} \end{aligned} \tag{13}$$

e) Minimum up/down time constraints:

$$[t_{ON,i}(t) - T_{ON,i}] \times I_i(t-1) - I_i(t) \ge 0 \tag{14}$$

$$[t_{OFF,i}(t-1) - T_{OFF,i}] \times I_i(t-1) - I_i(t) \ge 0 \tag{15}$$

3) Wind generator constraints:
a) Wind generation fluctuation constraints:

$$if \ \ P_{WT}(t-1) \le P_{WT}(t) \quad\ P_{WT}(t) - P_{WT}(t-1) \le TDR(t) \tag{16}$$

$$if \ \ P_{WT}(t-1) \ge P_{WT}(t) \quad P_{WT}(t-1) - P_{WT}(t) \le TUR(t) \tag{17}$$

b) Wind power curve constraints:

$$\begin{aligned} & if \ \ v(t) \le v_{I,j} \ \ or \ \ v(t) > v_{O,j} \qquad P_{W,j}^{*}(t) = 0, \qquad v_{I,j} \le v(t) < v_{R,j} \qquad P_{W,j}^{*}(t) = \varphi_j(v(t)), \\ & \quad v_{R,j} \le v(t) < v_{O,j} \qquad P_{W,j}^{*}(t) = P_{W,j}^{\max} \end{aligned} \tag{18}$$

c) Total available wind generation

$$P_{WT}^{*}(t) = \sum_{j=1}^{NW} P_{W,j}^{*}(t) \tag{19}$$

d) Total actual wind generation limit:

$$0 \le P_{WT}(t) \le P_{WT}(t) \tag{20}$$

(2)The Wind-Thermal Coordination Algorithm [14]

The wind model total actual wind generation at hour t is: $P_{WT}(t) = \min\{P_{WT}(t), P_{WT1}(t), P_{WT2}(t), P_{WT3}(t)\}$ (21)

Where $P_{WT1}(t) = \frac{\sum_{i=1}^{NT} US_i(t) - USR_B}{\gamma}$ $P_{WT2}(t) = \frac{P_L(t) - \sum_{i=1}^{NT} I_i(t) \times P_i^{\min}(t)}{1+\gamma}$ $P_{WT3}(t) = \frac{\sum_{i=1}^{NT} I_i(t) \times DS_i(t)}{\gamma}$

$P_{WT}(t) = P_{WT}(t-1) + TDR(t)$

CHAOS OPTIMIZATION PSO ALGORITHM

The basic PSO algorithm and its advantages and disadvantages

The basic PSO algorithm has two main aspects [15-19]:

(1) Initial population randomly makes pbest, and Update gbest lose clear goals, the convergence of the algorithm is greatly restricted.

(2) Individual speed and position update essentially relies on its own information makes the algorithm premature convergence is difficult to get the optimal solution.

The thought of Chaos optimization of PSO algorithm [16]

This paper through the fusion mechanism of chaos optimization, reduce strong dependence on initial value algorithm, the appropriate diversity of the algorithm, and also kept the PSO algorithm is easy to implement, fast speed, etc[20].

Specific ideas are as follows:

Firstly use the chaotic sequence to initialize the particle's position, select the location of the initial population positions in the amount of them, Then in particle update and imports the chaos optimization search, number of chaotic sequence are produced randomly and can get the location and the current particle optimal position, if it is better than the current particle, update the current particle optimal position, guiding the current particle jump out of local optimal point, to find the optimal solution quickly

In this article use the improved particle swarm optimization algorithm to solve target model, which realize the wind-thermal power random multi-objective scheduling, obtains each time more close to the actual situation of the power generation plan, to access a fairly large wind power system scheduling plan has practical reference significance.

So based on improved PSO optimization steps are below:

1. Setting Parameters for the improved PSO;
2. Chaos Initialize 2*pop_size positions;
3. For each chaos initialized position i;
4. Calculate fit (i);
5. Select the top pop_size positions as the positions of the initial swarm;
6. For each particle i in the swarm, randomly in initialize the velocity (i);
7. Set pbest equals fit i) and update p_besl (i) using pos (i);
8. Iif fit(i)<g_best, update g_best using fitl(i), update g_pos using p_best (i);
9. While iter less than iter_max, calculate fit (i);
10. While iter_chaossearch less than iter_csmax,

If the result of chaos_search better than this partiele, update the particle with the chaos_seareh position;

11. If fit(i) better than p_best(i) , update pbest with Fit(i) , update p_best(i) with pos(i);
12. If Ppbest better than gbest, update gbest with pbest, update g_pos with p_best(i);
13. Update the velocity (i) , update the pos(i) over.

Where pop_size—the population size, fit(i)—fitness of number i, velocity(i)—the velocity of particle i, p_best(i)--the best place to particles i, pbest--individual extreme, pos(i)—current position, g_best—populatiion extreme, gbest-- Best fitness of populations, g_pos--the optimal location population, iter_max--the largest number of iterations,iter_csmax-- Maximum chaos search times,

TEST SYSTEM AND DISCUSSION

Test System

To examine the effectiveness of the proposed algorithm, IEEE-10 nodes is considered. The system unit data and load demand are given in [21].

Tab 1 Set the parameters

parameter	Initial value
Learning actor	2.05
Inertial factor	0.729
Population size	20
Largest number of iterations	1000
Run number	50
Chaos control parameters	4
Number of Chaos optimization search	5

RESULTS AND DISCUSSION

Through the improved PSO algorithm can get the follows:

Tab 2 The calculation results

cost($)	Pollution emissions(ton)	Co-Ordination degree	solution Numbers
75917.33	2.2063	0.025103	X1
75978.67	2.2357	0.023500	X2
75981.00	2.2073	0.024169	X3
75974.74	2.1732	0.027613	X4
75983.33	2.1648	0.032116	X5
75991.42	2.1420	0.031005	X6
75971.67	2.0128	0.032310	X7
75975.03	2.1024	0.032115	X8
75993.33	2.0844	0.031295	X9
75993.13	2.0705	0.033772	X10

From table 2, we can know that the X10 non-inferior solution the coordination degree is the highest, about 0.033772, X10 each period of the output of generating unit as shown in Tab3

Tab3. The results of X10 non-inferior solution in each period of the output of generating unit

Time	P1(MW)	P2(MW)	P3(MW)	Time	P1(MW)	P2(MW)	P3(MW)
1	247.9	298.5	376.9	13	265.3	251.6	254.3
2	225.6	275.0	312.3	14	236.9	212.7	238.6
3	286.1	301.2	332.1	15	165.6	173.5	153.7
4	323.5	332.6	375.9	16	143.2	157.3	142.6
5	385.6	398.2	415.3	17	159.0	146.2	157.3
6	408.7	432.5	450.1	18	201.3	156.7	172.0
7	432.4	424.4	467.8	19	256.4	203.7	193.5
8	524.2	510.3	531.4	20	275.9	243.6	208.1
9	432.8	479.8	432.6	21	308.5	312.4	206.7
10	376.2	354.6	321.7	22	328.6	321.7	258.9
11	334.5	321.4	302.7	23	336.7	356.9	324.8
12	289.5	265.9	271.4	24	336.1	376.8	298.7

Algorithm analysis

From the above results of test system, we can find that using the improved PSO algorithm can obtain the highest coordination in the whole system and on the basis of coordination degree of the highest to determine the corresponding output plans can get the optimal benefits, including economic and environmental benefits, specific algorithm analysis indicators are as follows:

(1) The Distribution of Solution

The basic PSO algorithm solution of distribution coefficient is 0.7013, improved PSO algorithm solution of distribution coefficient is 0.9129, more close to 1, so the distribution of improved PSO algorithm is better.

(2) The Rate of Convergence

The convergence rate of the two algorithms is shown in figure 1 and figure 2

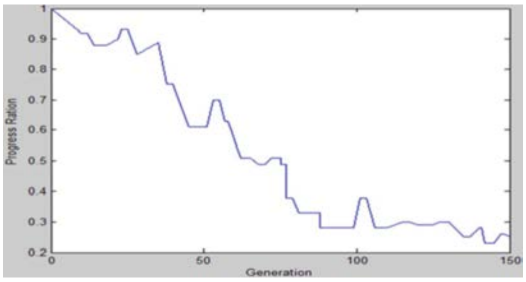

Fig1. Basic PSO algorithm progress rate curve

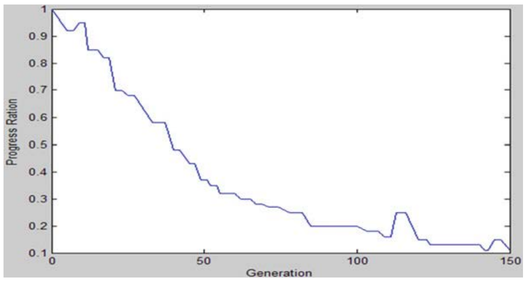

Fig2. Improved PSO algorithm rate curve

From Fig1 and 2, we can see that the improved PSO's convergent ratio is better than basic PSO, and improved PSO tends to have less iteration ultimately. It means that improved PSO algorithm has better convergence properties than basic PSO.

(3) Solution of the coordination degree
The improved algorithm can get the highest coordinate under the global optimal, then determined by the coordination degree of the highest solution generation schedule can get the best economic benefits.

The Discuss of Optimal Solution
Through the improved PSO algorithm obtain the highest coordination degree solutions and according to the pareto solutions available to the corresponding period of the output value. Because of the wind farm output has strong randomness, the actual power system needs to reserve to deal with the output of the upper and lower volatility and spare capacity also increases [22]. At this point, the thermal power unit can't completely according to the generating cost or pollution emissions of the optimal scheduling, and must be appropriate to consider its spare capacity increase. The costs of two algorithms are $75993.13 and $76829.37 respectively. It means the improved algorithm has better economic benefits.

Considering the wind power forecasting error of scheduling plan, the result already contains random effect of wind power will be more close to the actual state - thermal power scheduling, to the actual scheduling plan is more practical reference value.

CONCLUSION

This paper uses the improved PSO algorithm to solve the wind multi-objective coordinated problem of thermal power. Wind power output and power load are the main random factors in the power system. This paper modeling considering wind power to improve the algorithm search speed. Based on improved algorithm, the coordination of the solution of the highest degree can be calculated. Simulation results verified that the chaos optimization PSO algorithm has good practical value and practical guiding significance in real wind-thermal power system.

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