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FUZZY RANDOM CHANCE-CONSTRAINED PROGRAMMING BASED APPROACH TO ACTIVE-POWER-OUTPUT CALCULATION FOR WIND POWER FARMS

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ABSTRACT

Based on the fuzzy random chance-constrained programming(FRC) theory, the paper presents a method to calculate active-power-output of large-scale wind power farms connected to power grid. The calculation of active-power-output can be turned into a FRC programming problem which constrained conditions. This paper put forward a mathematical model of calculate active power in wind power integrated system based on FRC programming form. These include ramp constrains of the generating units, output restricted zone, line transmission capacity, reserved capacity constraints, the balance of load, and so on. The question is solved by particle swarm optimization based fuzzy simulations. The results on IEEE30 system demonstrate the advantages of the proposed approach.

Keywords: *Particle Swarm Optimization; Fuzzy Random Chance-Constrained Programming; Active-Power-Output; Large-Scale Wind Power Farms; Power Grid*

1. INTRODUCTION

Wind energy resources are clean renewable energy, Renewable energy has been increasingly embraced due to dwindling fuel reserves, and wind power generation is one of the most prospective new energy. Because of the fluctuation and intermittent of wind power generation, this fluctuant power will affect the power quality of the imbedded grid, such as voltage fluctuation and flicker. The active power output time-varying values of distributed wind turbines are important to supply and demand balance, generation ability and transmission ability.

The terrain and the different wind power installed capacity determine the position of wind turbine in large scale wind farm. The active power output varied with the fluctuation of wind speed, the wind speed-active power output data impact on the power grid[1]-[2].Now, the active power output calculation method based on Genetic Algorithm and hybrid intelligent algorithm has certain time lag characteristic, which is inaccurate to power dispatching and power quality management.

Based on the stochastic programming theory, the literature present a method to calculate maximum injection power of large-scale wind farms connected to power grid[3]. The literature introduces a new method for calculating wind power penetration limits in power system utilizing chance constrained programming[4]. A fuzzy random chance-constrained programming based hybrid intelligent algorithm for quantifying the transmission reliability margin (TRM) is presented in literature[5].The literature put forward a mathematical model of economic dispatch in wind power integrated system based chance constrained programming (CCP) and describes the related constrained conditions in probability form [6].

Most wind data constitute the particle swarm in solution space, which bing the uncertain problem, that is the optimum solution of wind farms active power output. This paper taken the maximum installed capacity as optimization objective, chosen the installed capacity and the output of unit as optimization variable. The constraint condition are composed of unit output constraint, power transmission limit of transmission line and the rotation reserved level of system. This paper put forward a mathematical model of calculate active power in wind power integrated system based on FRC programming form. These include ramp constrains of the generating units, output restricted zone, line transmission capacity, reserved capacity constraints, the balance of load ,and so on. The question is solved by particle swarm optimization based fuzzy simulations.

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2. THE ACTIVE POWER OUTPUT MATHEMATICAL MODEL INCLUDING WIND FARMS

The random variation of active power output in wind farms depends mainly on the fluctuation of wind speed and wind direction.the wind speed on axial fan hub must be obtained firstly if we want to calculate the active power output of wind farms. The wind speed on axial fan hub of wind turbines are different because of the wind wake effect and geographic location [7].

The arbitrary wind turbine may be occlused by upwind turbines in different extent.While calculating the input wind speed of wind turbine in wind farm, the interaction between different wind turbines must be considered.according to the law of conservation of momentum,the wind speed on axial fan hub can be described as:

$$v_j(t) = \sqrt{{v_{j0}}^2(t) + \sum_{\substack{k=1 \\ k\neq j}}^{n} \beta_k \left[{v_{w-k}}^2(x_{kj},t) - {v_{j0}}^2(t) \right]} \quad (1)$$

where, $v_j(t)$ is the wind speed of arbitrary wind turbine; $v_{w-k}(x_{kj})$ is the wind wake speed of NO. j wind turbine on the effect of NO. k wind turbine; v_{j0} is the wind speed of NO. j wind turbine without the effect of tower shadow; $\beta_k = A_{shad-jk} / A_{rot-j}$ is ratio of the No. k wind turbine projected area on NO. j wind turbine and the NO. j wind turbine area; n is total wind turbine number in wind farm.

The rated output power value of wind farm is equal to active power output, which is the output upper limit of wind farm. The active power output of wind turbine can be described as:

$$P_{ki} = \begin{cases} 0 & (v \le v_{CI} \text{or} v \ge v_{CO}) \\ \dfrac{P_R}{v^3_R - v^3_{CI}} v^3 - \dfrac{v^3_{CI}}{v^3_R - v^3_{CI}} P_R & (v_{CI} \le v \le v_R) \\ P_R & (v \ge v_R) \end{cases} \quad (2)$$

Where, P_R is rated output power of wind turbine; v is wind speed on axial fan hub; v_{CI} is cut-in wind speed; the automatic device incorporated wind turbine into power grid when the wind speed value higher than v_{CI}; v_{CO} is the wind cut-out speed, the wind turbine stop generation and detach from power system when the wind speed value higher than v_{CO} ; v_R is rated wind speed .

The active power output of wind farm can be described as:

$$P_k = \sum_{i=1}^{N} P_{ki} \quad (3)$$

3. FUZZY CHANCE- CONSTRAINED PROGRAMMING MATHEMATICAL MODEL

Chance-constrained programming is the important branch of stochastic programming, which is used in solving optimization problems of the uncertain factors in given confidence interval [8].

Supposing x is decision vector, ξ is fuzzy random vector, $f(x,\xi)$ is objective function, $g(x,\xi)$ is constraint function, $j=1,2,\cdots,m$, hance- constrained conditions as follows：

$$C_h\left\{g_j(x,\xi) \le 0,\ j=1,2,\cdots,m\right\}(\alpha) \ge \beta \quad (4)$$

where, α , β is confidence level.

Standard chance-constrained programming mathematical model as follows:

$$\begin{vmatrix} \max \bar{f} & \\ s.t. & C_h\left\{ f(x,\xi) \ge \bar{f} \right\}(\gamma) \ge \delta \\ & C_h\left\{ g_j(x,\xi) \le 0 \right\}(\alpha) \ge \beta_j \end{vmatrix} \quad (5)$$

where, $\gamma,\delta,\alpha,\beta$ is given confidence interval; $j=1,2,\cdots,m$.

If fuzzy random vector ξ degenerates to fuzzy vector, the mathematical model degenerates to:

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$$\begin{cases} \max \bar{f} \\ s.t. \quad prob\left\{ f(x,\xi) \ge \bar{f} \right\} \ge \delta \\ \quad\quad prob\left\{ g_j(x,\xi) \le 0 \right\} \ge \beta \end{cases} \quad (6)$$

where, $prob$ express the credibility measure of elements in set; $j = 1, 2, \cdots, m$.

3.1 Objective Function

Taking the maximum installed capacity as optimization objective:

$$\max f = \sum_{k=1}^{N_g} prob\left\{ P_k^{\max} \right\} \quad (7)$$

3.2 Constraint Conditions

Since the output power do not followed with velocity increase. When attach certain wind speed, the active power output of wind farm attain limited value on the effect of constraint condition which includes confidence level. The constraint conditions are composed of the power balance constraint of system, the rotating reserve constraint of system, the grade ability per minute constraint of system, the active power output constraint of transmission line, the output power constraint of conventional wind turbine.

System power balance constraint :

$$\sum_{i=1}^{N_g} P_i^g + \sum_{k=1}^{N_w} P_k^w = \sum_{j=1}^{N_l} P_j^l \quad (8)$$

System rotating reserve constraint:

$$\begin{cases} prob\left| \sum_{i=1}^{N_g} P_i^{g\max} - \sum_{i=1}^{N_g} P_i^g \ge R \right| \ge \beta_1 \\ R = \eta P^L \end{cases} \quad (9)$$

System gradeability per minute constraint:

$$prob\left| \sum_{i=1}^{N_g} R_I^{up} P_i^{g\max} \ge \sum_{K=1}^{N_W} \delta_k P_k^w \right| \ge \beta_2 \quad (10)$$

Transmission line active power output constraint:

$$prob\left| P_l^{l\min} \le P_l \le P_l^{l\max} \right| \ge \beta_3 \quad (11)$$

The output power constraint of conventional wind turbine:

$$P_i^{g\min} \le P_i^g \le P_i^{g\max} \quad (12)$$

where, N_w is number of wind turbine in grid; P_k^w is random variable, the active power output of wind turbine; N_l is the number of bus which access load; P_j^l is the power supply of bus; β_1 and β_2 and β_3 are given confidence interval; $P_i^{g\max}$ and $P_i^{g\min}$ are the upper and lower limit of conventional wind turbine; R is the rotating reserve active power output of system; η is the system reserved rate; P^l is total load; r_i^{up} is the active power output maximum allowed grade ability per minute of conventional wind turbine; δ_k is the possible maximum output power of wind turbine; $P_l^{l\max}$ and $P_l^{l\min}$ are the upper and lower limit active power output of transmission line l.

4. PARTICLE SWARM OPTIMIZATION BASED ON FUZZY CHANCE-CONSTRAINED PROGRAMMING

4.1 Particle Swarm Optimization

Particle swarm optimization originated from the research of birds swarm behavior[3]-[6], Application shows that compared with the genetic algorithm, the particle swarm optimization has the advantages of quick convergence and high forecast accuracy. the main characteristics of particle swarm optimization is:

1) Each individual is endowed with one random value which can flow in question space;

2) Individuals have memory function;

3) Individuals' evolution realize by cooperation and competition between individuals.

4.2 Stochastic Simulation Technique

Stochastic simulation technique provides a new and effective way to verify constraint condition, the realization process as follows：

Considering constraint conditions：

$$prob\left\{ g(x,\xi) \le 0, j = 1, 2, \cdots, k \right\} \ge \alpha \quad (13)$$

where, ξ is fuzzy variable; $\phi(\xi)$ is probability density function; given arbitrary decision vector

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x ,let $N_1 = 0$, the probability density function generate N random variables, substituted ξ and x to(13).If $g_j(x,\xi) \le 0, j = 1,2,\cdots,k$,then added 1 to N_1 ,according to law of large numbers when N is sufficiently large, if(13) is tenable, and only if is $N_1 / N \ge \alpha$ tenable. If $N_1 / N \ge \alpha$ is not tenable, which shows that the particles generated by particle swarm optimization inconsistent with the probability level of (13), such particle should be forsaken, generating new particle until all particles meet $N_1 / N \ge \alpha$.

4.3 Solving Process

According to the mathematical model in this paper, the work flow of particle swarm optimization is as follows：

1) Input the wind turbine numbers, wind turbine operation parameters, wind random distribution parameters.

2) Input the basic parameters of conventional power unit, such as: output limit , grade ability rate, reserve level ,etc.

3) Set the confidence level of constraint condition including random variable; input the basic parameters of particle swarm optimization, such as: iteration number, population size.

4) Calculate the active power output of wind farm according to the wind speed data of wind turbines measured. Testing the particles meet constraint condition including confidence level or not by using stochastic simulation technique, forming the initial positions and values of initial particle group which accord with population size.

5) Calculate the adapt value of each particle.

6) From(2),compared the adapt value of each particle with individual extremum, renewal current individual extremum is P_{best_i} if the result is better.

7) From(2),compared the adapt value of each particle with global extremum, renewal current individual extremum is G_{best} if the result is better.

8) Renewal position and velocity of each particle.

9) Repeat steps(5)～(8), till the data fitted the stop conditions.

10) Take the most suitable particle as optimal solution which is the active power output of wind power farm seeking.

5. ANALYSIS OF EXAMPLES

Taking IEEE 30-node system for example [7], supposing the wind farm access in system at node 16.there are sixty wind turbines in wind farm, the cut-in wind speed, cut-out wind speed, rated wind speed is respectively 4, 25, 15m/s. Supposing the wind turbine on node 11 and 13 are opened units, the output power of which is 0.2 pu, the wind turbine on node 1 is balance unit. the wind turbine on node 2,5,8 can automatic adjustment within limits of permit output power. The total active load is 3.561pu.

In order to verify the effectiveness of the algorithm, the active power output mathematical model is respectively solved by particle swarm optimization and genetic algorithm. Calculation results are list in graph1, the value of spinning reserve level is the 15 percent of system load, the maximum output power variation is the 30 percent of nominal capacity. Wind speed obeys Weibull distribution. Related parameters of wind turbines are list in Table1.

Table1 Units Parameters of IEEE30 Buses System

Wind turbine	Upper limit outpower(pu)	Lower limit outpower(pu)
1	1.39	1.30
2	0.58	0.32
13	0.25	0.20
27	0.17	0.10

Under the same confidence level, convergent expectation of active power output based on genetic algorithm is higher than particle swarm optimization by eighteenth iteration. Under the same convergence condition, the time of genetic algorithm is twice than particle swarm optimization, which shows that the efficiency in search for searching speed of particle swarm optimization, the performance of particle swarm optimization is better than genetic algorithm. Shown in figure 1.

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The first method： using genetic algorithm. β_1 and β_2 and β_3 are 0.95, expect the maximum active power output.

The second method： using particle swarm optimization. β_1 and β_2 and β_3 are 0.95, expect the maximum active power output.

The third method： using particle swarm optimization. β_1 and β_2 and β_3 are 0.90, expect the maximum active power output.

Table 2 Optimization Solution of Two Optimizations

Different methods	Active power output(pu)		
	1	2	5
The first method	0.8289	0.2618	0.2730
The second method	1.0820	0.14	0.1513
The third method	1.1747	0.14	0.1376
Different methods	Active power output(pu)		
	8	11	13
The first method	0.2269	0.14	0.14
The second method	0.217	0.14	0.14
The third method	0.1380	0.14	0.14

From Table 2, when the confidence level is changed(change 0.95 to 0.90) ,the active power output improved obviously, and vice versa.

6. CONCLUSION

Based on the randomness of wind farm, this paper put forward a mathematical model of calculate active power in wind power integrated system based on FRC programming. The question is solved by particle swarm optimization based fuzzy simulations, At last, an analyzation result about IEEE-30 system is given, The following conclusions can be drawn from the study.

Using the fuzzy chance-constrained programming mathematical model, the active power output can meet the constrained conditions.

Under the same convergence condition, the time of genetic algorithm is twice than particle swarm optimization, which shows that the efficiency in search for searching speed of particle swarm optimization, the performance of particle swarm optimization is better than genetic algorithm.

So, the particle swarm optimization is suitable for the active power output short-term forecast.

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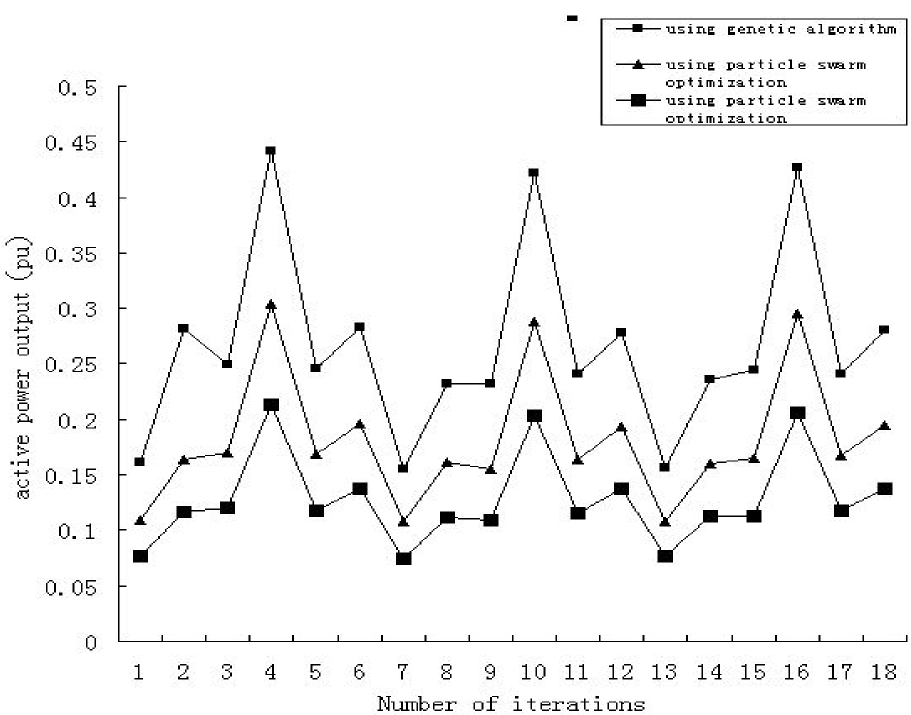

Figure 1 The Results of Wind Farm Active Power Output