TELKOMNIKA, Vol. 11, No. 8, August 2013, pp. 4433~4438
e-ISSN: 2087-278X

Research on the Wind Power Penetration Limit in Power System

Yang Zhang*[1], Hongbo Zhang[1], Degui Yao[2], Qiang Li[2]
[1]North China University of Water Resources and Electric Power, Zhengzhou, China, tel: 13939045521
[2]He Nan Electric Power Research Institute, Zhengzhou, China, tel: 13703710351
*Corresponding author, e-mail: 286554472@qq.com

Abstract

An approach to calculate the wind farm penetration capacity based on chance constrained programming combining with transient check was presented. A novel model for programming penetration of wind farm under indeterminacy operating mode was presented. Constraint condition consisted of conventional generator output limits, system spinning reserve, transmission lines capability, nodal voltage, system frequency etc, and genetic algorithm based on Monte Carlo simulating was used to solve the problem, and the actual sample system verified the feasibility of the model and method. Results for the application of this approach revealed the influencing factors of penetration of wind farm consisted of the parallel node voltage, the output variation range of wind generating set and mean wind speed etc. The research results have important practical significance, which can guide the actual wind farms in the planning and operation analysis of reality wind farm.

Keywords: *wind power penetration, chance constrained programming, monte carlo simulating, genetic algorithm, transient stability*

1. Introduction

With the proportion of the wind power in the power system increasing, the impact on the system is more and more prominent [1, 2]. The big change of the wind speed may bring greatly disturbance on the voltage, frequency and power angle of the system and the grid scheduling departments often make wind farms out of operation in case the system loss stability in severe cases. Therefore, the capacity of wind power penetrating into system becomes an important topic in the study of wind power.

This paper studied the capacity of wind power penetrating into system. The dynamic simulation method was often used to determine the capacity [3-8]. The first step is to set a value based on the experience and check the stability in typical operation mode. The second step is to adjust the value until the stability requirements are satisfied. This method is indirect verification and the computation is intensive, there also some other operation conditions are not considered [9]. In recent years, optimization method was mainly used in the research. It calculated the maximum capacity of the wind power in various constraint condition, so the full range of conditions were considered [10-13].

Because of the wind speed is uncertain and random variation amount, the output of the wind power is uncertain and it may leads to the changes of the output of the conventional unit, the system spinning reserve, the line power, node voltages and the system frequency. In this paper, chance constrained programming [14] was used to deal with the problem. It made the decision before the random amount such as wind speed and load was observed as long as the established probability brought by the decisions made by the constraint condition is higher than the given value. Due to the load and wind speed change at any time, some constraint conditions may not be satisfied in some Individual circumstances even if the probability of occurrence is low and in this case the integrating capacity we obtained is a smaller value, so the wind energy can not be maximize used. If some constraints were not satisfied in a low probability, the wind power capacity will be a larger value and the wind energy could be made full use of.

This paper presented a step-by-step method based on combining the chance constrained programming and dynamic calibration, the mathematical model of the wind power

Received February 11, 2013; Revised May 13, 2013; Accepted May 22, 2013

integration capacity was established. The developed genetic algorithm is based on the Monte Carlo simulation and obtained the desired results.

2. Research Method

There are three steps for solving the wind power integration capacity. The first step is the capacity optimization; the second step is the cutting machine optimization; the third step is the transient check. In the first step higher integration capacity value could be get in case the constraint condition was not satisfied in a lower probability. In the second step, cutting machine to satisfy all the constraints once constraint condition was not satisfied [10], and the optimization goal is the wind power with a maximum loading rate after cutting the machines, so the reserving wind turbine could take load as much as possible. The effect of the two step is the probability of wind energy integration capacity into system be higher, and maximizing the use of wind energy in case the constraint condition were not satisfied. The third step is to check the stability that obtained by the second step in a typical system operating mode to ensure the steady and transient operation are all stable after the wind power integrating into system.

2.1. Mathematical Model of the Wind Turbine

The active power characteristics of the wind turbine are expressed in piecewise function in the calculation, as shown in formula (1) below.

$$P_W=\begin{cases}0 & v\le v_{in} or v\ge v_{out} \\ \frac{P_R}{v_R^3-v_{in}^3}v^3-\frac{P_{Ri}}{v_R^3-v_{in}^3}v_{in}^3 & v_{in}\le v\le v_R \\ P_R & v\ge v_R\end{cases} \quad (1)$$

V is the wind speed at hub height; V_{in} and V_{out} are wind speed cut in and cut out; V_R is the rated wind speed; P_R is the rated power.

Wind speed obeys the Weibull Distribution, as shown in formula (2) below:

$$p(V)=\frac{k}{C}\left(\frac{V}{C}\right)^{k-1}e^{-(\frac{V}{C})^k} \quad (2)$$

K is the shape factor; C reflect the size of the annual average wind speed. Load distribution could take the normal distribution, uniform distribution or other distribution types.

2.2. Mathematical Model of the Capacity Optimization

The optimization objective is to maximize the installed capacity of wind farms. The constraints include power flow equations, the conventional unit output constraints, transmission capacity of the line power constraints, node voltage constraints, rotating reserve constraints and system frequency constraints.

Constraints of the flow equation and conventional unit contribution are the probability was satisfied with probability 1; constraints of the transmission capacity of the line power, node voltage, spinning reserve and system frequency are satisfied with a higher probability less than 1. The purpose is to exclude the condition that occurrence probability is very low but limiting the integration capacity of the wind farm in a larger extent. The capacity optimization mathematical model is expressed as follows:

$$\max \sum P_{Ri}$$

s.t.

$$P_{Wi}+P_{Gi}-P_{Li}=V_i\sum_{j=1}^{N}V_j(G_{ij}\cos\theta_{ij}+B_{ij}\sin\theta_{ij})$$

$$Q_{Wi}+Q_{Gi}-Q_{Li}=V_i\sum_{j=1}^{N}V_j(G_{ij}\sin\theta_{ij}-B_{ij}\cos\theta_{ij})$$

$$\begin{aligned}
&P_{Gi}^{l} \le P_{Gi} \le P_{Gi}^{h} \\
&Q_{Gi}^{l} \le Q_{Gi} \le Q_{Gi}^{h} \\
&p\{P_l^{l} \le P_l \le P_l^{h}\} \ge \alpha_1 \\
&p\{Q_l^{l} \le Q_l \le Q_l^{h}\} \ge \alpha_2 \\
&p\{V_i^{l} \le V_i \le V_i^{h}\} \ge \alpha_3 \\
&p\{\sum (P_{Gi}^{h} - P_{Gi}) \ge P_S\} \ge \alpha_4 \\
&p\{f^{l} \le f \le f^{h}\} \ge \alpha_5
\end{aligned} \tag{3}$$

i,j represents any node respectively in formula (3)；l represents any branch；P_R is the wind turbine rated power;P_W and Q_W are the active and reactive power of the wind turbine; P_G, P_G^l, P_G^h, Q_G, Q_G^l, Q_G^h are the active power, active power lower limits, active power upper limit , reactive power, reactive lower limit, reactive power upper limit of conventional units; P_L and Q_L are the active and reactive load power; V_i is the voltage of node i; G_{ij}, B_{ij}, δ_{ij} are the conductance, susceptance and voltage phase angle difference between node i and j ; P_S is the spinning reserve of the system; P_l, P_l^l, P_l^h are the ctive power, active power lower limit, active power upper limit of the line l; Q_l, Q_l^l, Q_l^h are the reactive power, reactive lower limit, reactive power upper limit of line l; f 、 f^l 、 f^h are the frequency, frequency lower limit and the upper frequency limit of the system. $\alpha_1 \sim \alpha_5$ are the probability values.

2.3. Optimization Mathematical Model of Cutting Machine

Optimization objective is maximizing the load carrying rate of the wind power after cutting machine.

The constraints include power flow equations, the conventional unit output constraints, transmission capacity of the line power constraints, node voltage constraints, rotating reserve constraints and system frequency constraints. All the constraints should be satisfied with probability 1. The aim is to give full consideration to various situations that limitting the wind farm capacity. Optimization mathematical model of cutting machine is expressed as formula (4):

$$\max \ \frac{\sum P_{Wi}}{\sum P_{Li}} \tag{4}$$

The constraint condition is similar to the formula (3) and the difference is that $\alpha_1 \sim \alpha_5$ are the value less than 1 in formula (3), but $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 1$ in the optimization mathematical model.

2.4. Solving Methods

Take wind power installed capacity as chromosome and test the adaptability of each chromosome using the Monte Carlo simulation technique, the process is shown as follows:

(1) Enter the primary data;

(2) Evolution generation initialized to zero and give the initial values of the population, the crossover rate and mutation rate;

(3) Modify the network parameters and start the flow calculation;

(4) Produce chromosome and applicate the Monte Carlo simulation technology to test the feasibility of chromosomes, sort the individual, inspect the constraint conditions;

(5)Output the best individual in case the evolution generation achieve the maximum value; Otherwise start to code, select, crossover, mutation and decode, then sub to step (3).

3. Results and Analysis of Sample System

The sample system was shown in Figure 1. Node 1 represents wind farm which connected with nodes 8 through transmission lines; The nodes 2, 3, 4, 5 represent conventional thermal power generating units and the total installed capacity is 1072.68MW,and the maximum load of the system is 682.5MW.The following analysis is to determine the optimal capacity of the wind farm of the system.

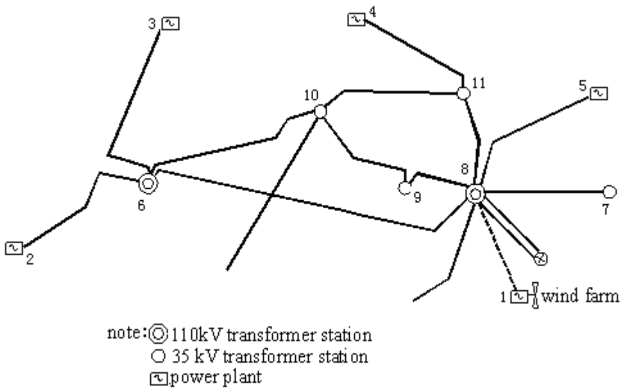

Figure 1. The Geographic Diagram of Sample System

3.1. Capacity Optimization

The node 8 represents 110kV bus and 35kV bus of the 110kV substation as shown in Figure 1, which is taken as parallel point. Parameters are set as follows: wind speed Weibull distribution parameter is k=2.0;The cut-in speed of wind turbine is 4m/s; $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 0.95$; The population size is 10; The maximum evolution generation is 100; The cross rate range is [0.5,0.9]; The scope of the mutation rate is [0.001,0.1]. The calculation results were shown in Table 1.

Table 1. The Calculation Results of Wind Power

Node 8 voltage grade	C=6, V_{out}=20(m/s)	C=6, V_{out}=25(m/s)	C=8, V_{out}=20(m/s)	C=8, V_{out}=25(m/s)
110kV	98.54(MW)	91.37	94.56	86.64
35kV	79.32	72.67	78.34	68.02

It can be seen from the Table 1 that the wind power integration capacity is greater when the range of the output of the wind turbine is smaller, the voltage level is higher and the average wind speed is smaller.

3.2. Wind Generating Set Cutting Optimization

Take the parameters equal to the value of the corresponding when calculation value is 98.54 MW. The calculation results were shown in Table 2.

Table 2. The Calculation Results of Wind Generating Set Cutting Optimization

The Genetic Generation Number of Optimum Value	Wind Power Capacity (MW)	Wind Power Active Power(MW)	Load Rate of Wind Power	Cutting off Rate of Wind Power
43	65.69	59.12	8.66%	33.34%

Table 2 showed that wind power penetration limit decreased by 33.34% when all the constraint conditions were meet compared to be meet with a certain probability, to explain the condition with minimum occurring probability (0.05) limitted the wind power capacity, which made the calculation results be conservative, lose a lot of wind.

3.3. Transient Check

1. Wind speed disturbance and fault mode

(1) Wind speed changes at the most drastic model: from the rated wind speed 14m/s down to cutting wind speed 4m/s within 2s.

(2) N-1fault:110kV lines between node 3 and 4 occur three phase short-circuit, cut off fault lines after 0.12s.

2. Check result

The normal operation with wind power 65.69MW

(1) Wind speed disturbances. The part of system node voltage variation curve was shown in Figure 2. System frequency and system typical unit relative angel change curve was shown in Figure 3. The Figure 2 and Figure 3 showed the voltage of part of the system unit appeared small-scope fluctuation after the gradient wind starting at 3s, then recoverde to normal level; And the paralleling node frequency keep in rated value, the typical unit relative angle fluctuated within a narrow range, then restored constant, so the system voltage, frequency, angle were stable after wind speed disturbance.

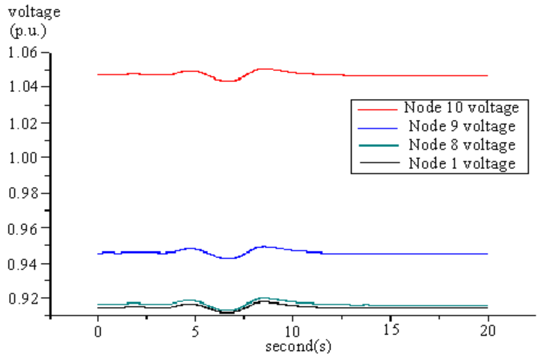

Figure 2. Nodal Voltage Curve under Wind Speed Disturbance

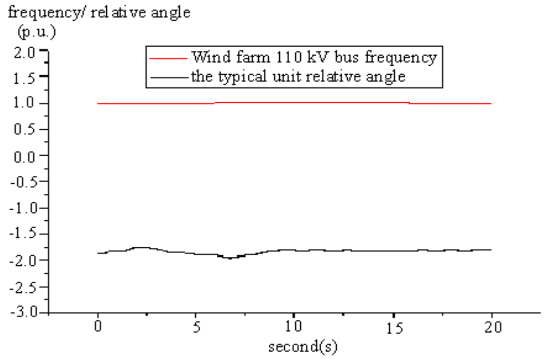

Figure 3. System Frequency and Power-angle Curve under Wind Speed Disturbance

(2) Fault disturbance the part of system node voltage variation curve was shown in Figure 4. System frequency and system typical unit relative angel change curve were shown in Figure 5. The Figure 4 and Figure 5 showed the voltage of part of the system were in the acceptable range (0.9p.u.~1.1p.u.) before short-circuit, but appeared large-scope agitation, then recovered to normal level after cutting off fault lines; And the paralleling node frequency keep in rated value, the typical unit relative angle fluctuated within a wide range during disturbance, then restored constant, therefore, the system voltage, frequency, angle were stable after fault disturbance.

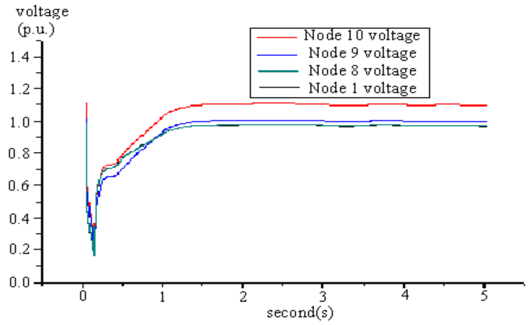

Figure 4. Nodal Voltage Curve under Fault Disturbance

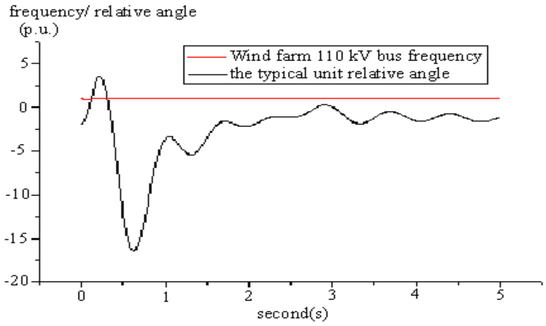

Figure 5. System Frequency and Power-angle Curve under Fault Disturbance

4. Conclusion

This paper established the optimization mathematical models of wind power penetration and cutting machine, and genetic algorithm based on Monte Carlo simulating was used to solve the problem. the analysis of practical example showed that the influencing factor of penetration of wind farm consist of the parallel node voltage, the output variation range of wind generating set and mean wind speed etc. The wind power capacity equals to the optimized capacity value in case of high probability operation condition; otherwise equals to the cutting machine optimized capacity value. Thus the stability of the transient process of the system can be guaranteed, and making the best use of wind power. Research conclusion can direct the programming and operation of reality wind farm.

Acknowledgements

Foundation item: Natural science advanced project programs funded by education department of Henan province (2010A470004).

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