Study on the Effect of Wind-Thermal Installed Capacity Ratio on the Stability of DC Islanded System

SHA Zhicheng[1, a] , WANG Yan[2,b] , ZHENG Shuai[1,c] and Dong Jingfang[3,d *]

[1] Shandong Electric Power Engineering Consulting Institute Corp, Ltd., China

[2] Shandong Power Economic Research Institute, China

[3] School of Electrical Engineering, Shandong University, China

[a]shazhicheng@163.com, [b]wangyan@sdepci.com, [c]zhengshuai@sdepci.com, [d]lkjun@sdu.edu.cn

Keywords: wind-thermal-bundled, UHVDC, island operating mode, stability

Abstract. Wind-thermal-bundled power transmission by UHVDC system is regarded as one feasible way of developing global clean energy in the future and its characteristic of stability should be paid attention to. Different wind-thermal installed capacity ratio is proposed with the wind from the change of power angle and in consideration of the probability for wind power output. The effect of two kinds of proportion on the stability of the sending end islanded system was comparatively analyzed by the simulation. Regulating ability of sending end power would be lower when wind-thermal installed capacity ratio decreased from 1:2 to 1:1.5. Under DC power system disturbances and loss of parts of power, there was a slight increase in ascending amplitude of system frequency, risk of frequency violation will rise accordingly.

Introduction

With the rapid growth of national economy, how to ensure the sustainable supply of energy is an important challenge for China. With the background of economic globalization, international cooperation has gradually expanded into various fields of energy industry. To actively carry out international energy cooperation has become an important strategic choice for countries to ensure energy security. Russian Far East is rich in coal resources and has immense potential for wind energy. The introduction of Russian Far East Electric Power has a positive effect to reduce the pressure of coal transportation and environment of China[1].

Taking into account reserves, technology development conditions, and the Sino Russian border distance, infrastructure and other factors comprehensively, we can focus on the coal and wind power resources of Amurskaya Oblast and Habar. So far some domestic enterprises have developed the preliminary work in the area. They plan to construct a coal mine with an annual output of 4000 tons and 14 ~16 660MW Thermal Power Units. At the same time, they plan to develop the nearby wind power resources and send electricity to China in the way of wind-thermal-bundled. As the distance between Russian Far East and the nearest North China load center is more than 2500km and the transmission capacity is about 11000MW, we should give priority to the use of 1100kV UHVDC transmission technology as the transmission scheme[2].But the existing power generation capacity and power grid structure of Russian Far East cannot meet the requirements of this project, this project should adopt island operating mode with the way of point to grid power supply to China , which is called 'Special factory, Special line'.

In the wind-thermal-bundled transmission system, the impacts of different wind-thermal installed ratio on the grid transient stability depend on system topology and operation mode[3,4]. This paper presents a scheme of wind power and thermal power capacity ratio based on the change of wind power. Then this paper presents different proportioning scheme considering the wind power output probability and make a study of effect of two kinds wind-thermal installed capacity ratio on stability of sending end islanded system by a comparative analysis of the simulation.

Scheme Of Wind-Thermal Installed Capacity Ratio

The research shows that the wind power output of each wind farm is significantly correlated in the long time scale, and in short time scale, the complementarity is obvious. For large wind power bases, the geographical position of the wind electric field distribution is relatively concentrated andthe change tendency of each wind farm output is similar under large areas of wind in a long time. In a long time scale, different wind power output in wind farm shows a significant correlation, causing the large fluctuation of entire wind power base in the total output[5]. In the short time scale, the dispersion effect of wind turbines in geographical distribution can reduce the correlation of wind power output and improve their complementarity. So the wind power output fluctuation characteristics of large-scale wind power base or wind farm group is much smaller than that of single wind farm or single unit[6].

Effects of fluctuation of wind power output in short time scale on wind-thermal installed capacity ratio. In the case of the DC power supply side taking the island operating mode, in order to ensure the DC power's stability, the speed of the thermal power unit should be able to track the short-term fluctuations of wind power output. Due to the lack of statistical characteristics of short time wind power in the Far East, the wind power output characteristics of large-scale wind power base in China are analyzed qualitatively. According to the actual operation experience of wind power in Jiuquan, the output change rate of single wind farm group is about 2.04~7.14%/min, while for the whole Jiuquan wind power base, the output change rate is about 0.69~1.80%/min. Statistics show that the probability of wind farm output change rate in 0~0.6%/min is about 90%, probability within 0~1.5%/min about 99%, probability more than 1.5% about 1%[7].

In general modern thermal power unit output response rate can reach 2~3%/min of rated output, and the qualitative analysis shows that when the wind power and thermal power capacity ratio is more than 1:1, regular fire unit is capable of tracking the fluctuation of wind power in a short time scale and achieve the active power balance and ensure the quality of the frequency.

Effects of fluctuation of wind power output in long time scale on wind-thermal installed capacity ratio. In order to ensure the stability of the DC power and the wind power transmission, the thermal power unit should have sufficient rotating reserve capacity and ensure that the wind power output is large enough to reduce the loss of wind[8].In order to meet the power change of wind power in the long time scale, the wind power output and thermal power capacity should meet the following relationship:

$$P_{fire.N} = P_{fire.R} + P_{fire.min} \tag{1}$$

$$P_{fire.R} \geq P_{wind.max} - P_{wind.min} \tag{2}$$

Where $P_{wind,max}$ and $P_{wind,min}$ represent maximum output and minimum output of wind power respectively. $P_{fire,N}$ is installed capacity of thermal power unit. Because the conventional thermal power unit is limited by the minimum technical output, it is decomposed into the minimum output and adjustable capacity:

$$P_{fire.N} = P_{fire.min} + P_{fire.R} \tag{3}$$

From a long time scale, the wind power output is usually within the range of zero to the rated output $P_{wind,N}$. Considering the most serious situation: $P_{wind,min}=0$, $P_{wind,max}=P_{wind,N}$, then the adjustable capacity of the thermal power should be satisfied:

$$P_{fire.N} \geq P_{wind.N} \tag{4}$$

At present, the minimum technical output of large thermal power units can reach 50% or lower. At this time, the choice of wind and fire capacity ratio is:

$$\frac{P_{wind.N}}{P_{fire.N}} = \frac{1}{2} \tag{5}$$

From the practical experience of China's large-scale wind power bases, they rarely reach the full capacity. Therefore, this project proposes a fire capacity ratio selection scheme which considers the wind power output probability.

The annual cumulative probability distribution of wind power output in the Far East area is drawn based on the typical daily wind speed data, it can be seen that the probability of wind power output greater than 90% of the rated capacity is low. So it can be inferred that when the regulating capacity of thermal power units can track the change of wind power in the range of zero to 90% rated output power and the loss of abandoned wind will be very small. For the quantitative analysis of the relationship between wind capacity ratio and supporting units to stabilize the wind power fluctuation range, using ε to represent probability of wind power output between $P_{wind,\alpha,min}$ and $P_{wind,\alpha,max}$:

$$F_{(P_{wind.\alpha.min} \leq P_{wind} \leq P_{wind.\alpha.max})} = \varepsilon \tag{6}$$

The definition of a reliable factor is as follows:

$$\alpha_\varepsilon = \frac{P_{wind.\alpha max} - P_{wind.\alpha min}}{P_{wind.N}} \tag{7}$$

The general selection of $P_{wind,\alpha,min}$ is 0. Then after ensuring ε, it is able to get $P_{wind,\alpha,max}$ according to the probability distribution of wind power output and reliability factor.

For the convenience of the description, using β to represent the proportion of minimum technical output of the power supply unit of the installed capacity:

$$\beta = \frac{P_{fire.min}}{P_{fire.N}} \tag{8}$$

Making a comprehensive consideration to formula (2) and formula (7), we can know that to meet the output variation of wind power under a certain probability ε, thermal power units' adjustable capacity in sending end should meet:

$$P_{fire.R} \geq \alpha_\varepsilon \cdot P_{wind.N} \tag{9}$$

The matching thermal power and wind power installed capacity ratio can be got by the formula (3) and type (8):

$$\frac{P_{fire.N}}{P_{wind.N}} = \frac{\alpha_\varepsilon}{1-\beta} \tag{10}$$

Based on the cumulative probability distribution of wind power output in the Far East as shown in Figure 2, different wind-thermal capacity ratio was calculated under the different probability, as shown in table 1.

Table 1. Wind-thermal capacity ratio under the different probability

E(%)	$P_{wind,\alpha,max}$	$P_{wind,\alpha,min}$	β	α_ε	Wind-thermal ratio
99.2	0.9	0	0.5	0.9	1:1.8
95	0.82	0	0.5	0.82	1:1.64
90	0.75	0	0.5	0.75	1:1.5

From table 1, in order to stabilize the 90% probability of wind power output change, wind-thermal capacity ratio required for 1:1.5.

Scheme Of Generator Installed Capacity Of Sending End

In order to ensure the stable operation of DC transmission system when DC island sends end power and a certain utilization hours, the sending end power capacity configuration should meet the demand of DC economic operation. The Far East to North DC transmission power is 11000MW. According to following preliminary estimate formula of installed capacity of wind power and thermal power:

$$P_{DC} \cdot T_{DC} = P_{fire} \cdot T_{fire} + P_{wind} \cdot T_{wind} \tag{11}$$

According to experience, DC transmission engineering utilization hours are about 6000h. Considering the thermal power utilization hours are 4500 ~ 5000h, far east wind power utilization hours are 4000h. Based on the results of the second chapter, wind-thermal installed capacity ratio is estimated as 1:2, and preliminary estimate of the capacity of the Far East to North China DC supporting wind power installed capacity is 5000MW. Thermal power installed capacity 15×660MW. If the installed capacity of wind power and thermal power ratio is 1:1.5, then the wind power installed capacity is 6000MW with 14×660MW of thermal power installed capacity.

Table 2. Sending end power capacity in different wind-thermal ratio

Wind-thermal ratio	Generator	Installed capacity（MW）	Capacity configuration （MW）
1:2	thermal	9900	15×660
	wind	5000	One unit：3
1:1.5	thermal	9240	14×660
	wind	6000	One unit：3

Effect Of Wind-Thermal Capacity Ratio On System Stability

In view of the DC island power supply system, making simulation calculation on sending end DC system fault and wind power fluctuation and other faults or disturbances to check the stability of the sending system.

Due to the operating characteristics of the system, the frequency of the system is greatly influenced by the frequency of the system. In the absence of the measured parameters of the speed control system of the unit, by using the measured excitation and governor system parameter of Hulunbeier Liaoning DC sending end supporting calculation of thermal power units.

Effect of DC system fault on sending end stability. *DC unipolar locking*. Once unipolar locking failure occurs in DC system, taking 10 cycle resection of wind turbines and 15 cycle resection of residual thermal power units of measure, commutation bus voltage will rise to a peak of 1.44p.u and system frequency is up to 51.16Hz. Taking 10 cycle to resect the thermal power unit measures, the highest converter bus voltage is 1.44p.u. The maximum voltage of the wind turbine is up to 1.22, and system frequency is up to 51.1Hz. System can maintain stable operation. Frequency and voltage are in the acceptable range.

Two DC bipolar commutation failure. The DC system can withstand two bipolar commutation failure with the system frequency and voltage still in the acceptable range. Converter bus voltage is up to 1.40p.u., while the maximum voltage of the wind turbine is up to 1.36p.u.. But the time of ending voltage of the machine which is up to 1.3p.u. is only one cycle. At the same time, wind power unit has not been removed and the highest frequency of the system rise to 50.95Hz.

DC restart once successfully. After DC unipolar restart successfully, the highest system frequency rise to 51.8Hz, exceeding the scope of the power generation equipment. The time of frequency which is more than 51.5Hz is 2s. The bus voltage is in the acceptable range, and the converter bus voltage is up to 1.18p.u.. The terminal voltage of the wind turbine is up to 1.12 p.u..

The system frequency is over limit after the DC single pole fault restart successfully, which can avoid the time when the generator set is protected by the high cycle cutting machine. On the other hand it can also consider the use of short-term overload capacity of the DC pole to the other(1.2p.u./3s), taking another pole power to the 1.2p.u. of rated capacity of emergency, and 3s after the power recovery measures, the maximum frequency of the system is not more than 51.5Hz.

Sensitivity analysis. Making stability check analysis of the situation when the wind power and thermal power capacity ratio of 1:1.5, DC system fault stability calculation results are as shown in table 3.

Table 3. The calculation results when wind-thermal bundled ratio is 1:1.5

Fault type	System frequency (Hz)	Converter bus voltage (p.u.)	Terminal voltage of wind turbine (p.u.)	Remarks
Unipolar locking and cutting wind turbine	51.17	1.41	1.29	
Unipolar locking and cutting thermal turbine	51.22	1.41	1.29	
two bipolar commutation failure	50.98	1.28	1.15	
Unipolar restart successfully once again	51.92	1.11	1.2	Time of frequency which is over 51.5Hz is 3.27s
A monopole successful restart (using another pole overload capacity)	51.55	1.19	1.11	Time of frequency which is over 51.5Hz is 0.2s

Calculation shows that when wind-thermal-bundled ratio decreased to 1:1.5, the sending end power regulating capacity decreased. Occurred in HVDC system fault for the loss of power, the system frequency increases slightly with the increasing of the risk of instability. After unipolar DC system restart successfully, sending end system frequency is over limit. Even taking measures using the other pole short-term overload capacity, it is still can't control frequency to less than 51.5Hz.

Effect of wind power fluctuation on the stability of the sending end. Power output has volatility and uncertainty. On the one hand, there are power fluctuations under the conditions of normal operation. On the other hand it also exists possibility of big area off accident due to system operating condition variation or adverse wind conditions and other factors.

This section is mainly to check the wind power off grid accidents and wind power fluctuations.

Large-scale wind power generators are taken off from grid. According to the maximum output of wind power for the 63% calculation of the installed capacity, the total wind output from the Far East to North China DC power of sending end is 3150MW. When it occurs that large-scale wind power generators are taken off from grid, after losing all the wind power, by using DC downhill control measures, the minimum system frequency is 49.57Hz and the converter bus voltage is up to 1.05p.u.. When wind-thermal capacity ratio is 1:1.5, after taking the same measures, the lowest system frequency is 49.45Hz and converter bus voltage is up to 1.08p.u.. The frequency and voltage of the system can be controlled in an acceptable range.

Wind power fluctuation. Wind speed variation has a strong randomness, but the increase or decrease of wind speed has a change process. The simulation using wind fluctuation simulates the normal operation of the wind power fluctuation caused by wind speed change in 1min.

In the large wind power bases, the dispersion effect of the wind turbine in the geographical distribution will greatly reduce the correlation between wind turbine output. Therefore, the total output of wind power base or wind farm group is much smaller than that of single wind farm or single unit. According to the actual operation experience of wind power in Jiuquan, the probability of wind farm's output change rate is about 90% in 0.6% to 0 per minute. In each minute probability of 0 ~ 1.5% is about 99% and more than 1.5% of the probability is about 1%[9].

At present, it is short of the statistical characteristics of wind power output in DC sending end, and in the light of the statistical data of wind power characteristics of large wind power base in Jiuquan, Gansu, the wind power fluctuation in the Far East area is simulated.

Due to reflection of the power of the whole wind power base, the main reference wind power variation amplitude is caused by the wind speed.

The gust duration is 60s. The Maximum wind value is 0.4m/s. It causes the change of wind power output in the Far East area which is 376MW, accounted for the proportion of wind power installed capacity of 7.5%. Under the control of the matching of thermal power units, the maximum frequency of the sending ends to 50.48Hz. When wind-thermal capacity ratio is 1:1.5, the change of wind power output in the Far East area is 448MW. Similarly, in the matching of thermal power units under the regulation, the highest frequency of sending terminal is 51.5Hz. Both the system frequency and

voltage can be controlled in an acceptable range.

Summary

Researching the effect of different wind-thermal ratio on DC island sending end system is significant. This paper carried out simulation calculation and stability check to DC system fault of sending end and wind power fluctuation and other faults or disturbances.When wind-thermal ratio is 1:2, under the condition of full power operation, the system can withstand two successive commutation failures. When single pole fault happens, it immediately shuts down the fault pole, and at the same time, it can meet the requirement of safety and stability. The system frequency is beyond limit after the single pole fault restart successfully, but the time of frequency which is over 51.5Hz is short, by taking advantage of the other pole short-term overload capacity measures to control frequency within 51.5Hz. When large scale wind power generators are taken off from grid, after losing all wind power, the control measures of DC power downhill are taken. When the wind power output ratio variation of installed capacity in 1min is about 7.5%, the ability to regulate the frequency and voltage of power facilities, the system can be controlled within acceptable limits.

After HVDC system's wind-thermal bundled ratio reduced from 1:2 to 1:1.5, self-regulation ability of sending end generator has lowered. After loss of partial power of the DC system when fault happens, the frequency of the system increases slightly, which increases the risk of the frequency limitation.

References

[1] LIU Zhen-ya. China electric power and energy[M].Beijing: China Electric Power Press,2012.

[2] LIU Yang, ZHOU Ming, XIANG Meng, et al. Total transfer capability calculation for regional power systems with HVDC connected with large scale wind power[J]. Power System and Clean Energy, 2013,29(2):48~53.

[3] CAO Xi-min, LIU Tian-qi, LI Xing-yuan, et al. Influence of wind-thermal installed capacity ratio to wind-thermal bundled system transient stability[J]. East China Electeic Power, 2014, 42(5): 53~58.

[4] TANG Yi, ZHAO Li-li, GUO Xiao-jiang, et al. Impact of wind power penetration on angle transient stability of wind-thermal combined system[J]. Automation of Electric Power Systems, 2013, 37(20): 34~38.

[5] LIU Chun, LV Zhen-hua, Huang Yue-hui, et al. A new method to simulate wind power time series of large time scale[J]. Power System Protection and Control, 2013,41(1): 7~13.

[6] ZHAO Bing, LI Hong-bo, JIANG Da-wei, et al. Study on output power characteristics of wind farm group[C]. Proceedings of the twenty-fifth Annual Academic Conference on power systems and automation in China. Nov.2009.

[7] XIAO Chuang-ying, WANG Ning-bo, DING Kun, et al. Power characteristics of Jiuquan wind power base[J]. Automation of Electric Power Systems, 2010, 37(17): 64~67.

[8] HUANG Qiang. Research on active power balance problem of power system with large-scale wind power connection[J]. Power Construction, 2013,34(4): 27~31.

[9] XIA Tian, ZHA Xiao-ming, QIN Liang, et al. Statistical analysis of extreme wind power ramp-down events[J]. Power System Protection and Control, 2015, 43(7): 7~15.