Study on the Influence of Wind Power Uncertainty on Dynamic Stability of Power System

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Abstract. Due to the uncertainty of wind power generation, the access of high proportion of wind power has a negligible impact on grid operation. This paper analyzes the mathematical model of each part of wind power plant by modeling, analyzing the main influence of wind power uncertainty on the power grid, using Hexi power grid as background, using PSASP software to simulate and analyze the impact load of the power grid and the impact load at the same time and fluctuations in system voltage under gust disturbances. The simulation results indicate the risk indicators of the system's anti-interference ability.

Introduction

According to the national medium and long-term plan, China will build 8 million kilowatt-class wind power bases in Xinjiang Hami, Gansu Juquan, Mengdong, Mengxi, Hebei, Jilin, Jiangsu and Shandong in 2020. By then, the total installed capacity of wind power will exceed 200 million kilowatt. In this context, China's wind power has developed rapidly in recent years, and its development scale and development speed are in a leading position in the world. The problem of voltage stability has been widely concerned all the time. In the large-scale grid-connected wind power generation, wind power generation itself has uncertainties. The voltage collapse and voltage instability often cause serious economic losses.

Impact load has a very large impact on the entire power system, which will threaten the stable operation of the system and affect the safety of power equipment for a long time, resulting in equipment aging.

Because wind energy is uncontrollable, it changes all the time. It poses a huge challenge to the stable operation of power grids with large-scale wind farms. It also faces the influence of impact load. Therefore, it is very necessary to study the system under two kinds of disturbances. Anti-jamming capability. Literature [5] studied the dynamic model area of wind turbines. Literature [6] compares and analyzes the reliability of the grid under both shock load and conventional load, it obtains the impact of impact load on grid operation risk. In [7], the actual grid is simulated and calculated. The wind speed disturbance and the impedance value of the wind farm access system are compared to compare the degree of system voltage transient stability, and the conclusion of the voltage stability of the regional grid after wind power access is obtained. It is impossible to simulate two uncertain factors in the actual power grid and the impact on the stability of the power system.

Based on the background of Gansu Hexi Power Grid, this paper establishes a dynamic mathematical model of wind farms, analyzes the impact of wind farms on the power grid, and uses PSASP software to calculate the tidal current and steady state of Hexi Power Grid, simulating the node's impact. The voltage changes under the load and the wind farm is disturbed by the gusts. The purpose is to provide certain guidance and early warning for the high-level new energy grid-connected operation.
Wind Power Uncertainty has a Major Impact on Grid Operation

As an uncontrollable energy source, wind energy has the characteristics of randomness and intermittency. It changes all the time. In addition to internal uncertainty, wind power system also includes external uncertainties such as load and fault.

The impact of the wind farm on the entire system is mainly for the voltage stability of weak systems. When the asynchronous generator is running, it will obtain reactive power from the system to excite, which will cause changes in output power and voltage, which will affect the voltage quality and voltage stability of the power grid. Power fluctuation is the fundamental cause of voltage flicker and fluctuation. The reason, internal and external uncertainty is an important factor in determining voltage fluctuations. When the reactive power compensation device works, the voltage gradually recovers, and when the voltage is low, the reactive power compensation is greatly reduced, and the reactive power demand for the power grid is increased, which easily causes the voltage to collapse. The impact on voltage is mainly concentrated on voltage fluctuations, voltage flicker, etc.

Wind Power System Modeling

To study the operating characteristics of wind farms connected to the grid and their impact on the grid, an accurate wind field model must be established. The wind turbines mainly include wind speed model, wind turbine model, asynchronous generator model and transmission system model.

Gust Model

This paper mainly simulates the impact on the system under the influence of gusts. Therefore, only the gust model is established in the wind speed model. The gust is used to illustrate the characteristics of sudden changes in wind speed.

\[
V_c = \frac{V_{\text{max}}}{2} \left(1 - \cos 2\pi \left[\frac{t}{T_g} - \left(T_{1g} - T_g\right)\right]\right)
\]

\[V_{\text{max}}\] maximum gust, \[T_{1g}\] start time for gusts, \[T_g\] gust cycle

Wind Turbine Model

Mechanical torque generated by wind driven in fixed pitch fans.

\[
T_m = \frac{0.5\rho R^2 V^3 C_p(\lambda, \beta)}{\lambda P_n} \times 10^{-3}
\]

\[\rho\] air density \(\text{Kg} / \text{m}^3\), \[V\] wind speed \(\text{m} / \text{s}\), \[R\] wind wheel radius \(\text{m} / \text{s}\), \[\lambda\] tip speed ratio \[\lambda = \frac{QR}{V}\], \[C_p\] Wind energy utilization factor, \[\Omega\] the rated mechanical angular velocity of the wind turbine \(\text{Rad} / \text{s}\), \[P_n\] rated power \(\text{MW}\).

According to Bates theory the maximum \[C_p\] is 0.593. In actual engineering, the relationship between tip speed ratio \[\lambda\], pitch angle \[\beta\] and wind energy utilization coefficient \[C_p\] can be approximated by Heier.

\[
C_p = C_1 \left(C_2 - C_3 \beta - C_4 \beta^2 - C_5\right) e^{-C_6}
\]

Including \[C_1 = 0.5\], \[C_2 = \lambda\], \[C_3 = 0\], \[C_4 = 0.22\], \[C_5 = 5.6\], \[C_6 = 0.17\lambda\], \[\alpha = 2\].

This is a function fitted by the actual measurement data of the fan, which can meet the application of the project.

Conveyor Model

The transmission system is an important device for connecting wind turbines and generators, which
consists of a hub, a drive shaft and a gearbox. The equation of the transmission mechanism:

\[
\frac{dM_m}{dt} = \frac{1}{T_k} (M_{ae} - M_m)
\]

Where: \(M_{ae}\) for input torque, \(M_m\) for the transmission system output torque, \(T_k\) is the inertia time constant.

**Asynchronous Generator Mathematical Model**

The actual wind field in Hexi area basically adopts the doubly-fed asynchronous generator to establish its mathematical model, assuming (1) ignoring the effects of material saturation, hysteresis, eddy current and the skin effect of the line; (2) assuming sine in the air gap of the motor Distributed magnetic potential; (3) Assume that the rotor is smooth, regardless of the effect of the cogging.

In electromechanical transients, the asynchronous generator mathematical model:

\[
\begin{align*}
    u_d &= -R_d I_d + X' I_q + E_d, \\
    u_q &= -R_q I_q - X' I_d + E_q, \\
    T_0 \frac{dE_d'}{dt} &= -E_d' - (X' - X) I_q - 2\pi f_0 s T_0 E_q', \\
    T_0 \frac{dE_q'}{dt} &= -E_q' - (X' - X) I_d + 2\pi f_0 s T_0 E_d'.
\end{align*}
\]

The subscript in the formula d is the direct axis component, and the subscript q is the cross component, s is the slip coefficient of the generator. \(X\) is the synchronous reactance and \(X'\) is the transient reactance, \(T_0\) indicating the time constant of the rotor winding when the stator winding is open.

**Steady State Model**

The selected unit is a doubly-fed asynchronous induction unit. In the calculation, the wind farm is regarded as a PQ node, the active power and reactive power of the wind turbine are calculated according to the given wind speed and power factor, and then added as a normal load node to the power flow program.

**Transient Model**

The transient simulation calculation uses PSASP. Based on the steady state calculation, the wind power model developed by its user program interface (UPI) function is used for transient stability calculation.

**Numerical Simulation Analysis**

**System Model**

According to the actual power grid model in Hexi area of Gansu Province, the electric network structure is shown in Figure 1. The system has a base capacity of 100 MVA and contains 7 large-scale factory stations. The total capacity of the Gangan wind farm is 600 MW, which is wind farm in north of Gangan, wind farm in west of Gangan, wind farm in east of Gangan, each 200MW, due to its unique topographical climate advantage, the annual wind is sufficient, 45km away from Dunhuang of Gansu (31) 330kv substation, the line type adopts LGJ-2*300 line, and passes 6*LGJK400 line and Dunhuang of Gansu (71) substation Connected, the Gansu wind farm group with an average distance of 1000km from the Lanzhou load center is a typical long-distance transmission project.
Analysis of Grid Voltage Variation under Impact Load

Considering that the system is only subject to external uncertainty factors: the fluctuation of the system voltage during the impact load, the simulated node puts the impact load at the Dunhuang of Gansu (71) node, and starts to input \( P=100\text{MW}, Q=20\text{Var} \) at 10s; \( p=150\text{MW}, Q=20\text{Var} \) load, 40 seconds after resection, substation Gan Dunhuang (71) voltage fluctuations as shown in Figure 1.

Figure 1 shows that when the step change occurs at the Dunhuang of Gansu (71) node, the voltage drop is large, and then gradually recovers. Before the load is removed, the voltage has basically risen to the point where it is not disturbed. When subjected to an impact load of \( p = 150 \text{MW} Q = 20 \text{Var} \), the voltage recovery capability is weak.

Long-distance load end west Lanzhou of Gansu 31 substation voltage fluctuations as shown in Figure 2.

Figure 2. Voltage variation of Dunhuang of Gansu 71 substation under impact load.
It can be seen from Figure 2 that after the node is disturbed, the voltage fluctuates but the value does not change substantially, and the voltage fluctuation is negligible.

Power terminal: wind farm in north of Gan gan voltage fluctuations are shown in Figure 3.

As can be seen from Figure 4, the voltage of the wind power plant drops when subjected to the impact load, and then the voltage gradually recovers under the action of the reactive power compensation device, and the voltage of the wind power plant does not return to the undisturbed point before the load is removed. Under the impact load of $p=150$MW $Q=20$Var, there was no large fluctuation after 18 seconds in the voltage drop process, but the recovery time was longer.

**Analysis of Grid Voltage Variation under Impact Load and Gust Disturbance**

When the $p=160$MW and $Q=20$Var load were impact the systems are crashed, the simulation picture cannot be generated. Further, the problem of system voltage dynamic stability is explained. Considering the voltage fluctuation of the system when the system is subjected to external uncertainty factors (impact load) and the internal uncertainty factor (wind disturbance), the system

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![Figure 3. Voltage variation of Lanzhou West 31 substation under impact load.](image)

![Figure 4. Voltage variation diagram of wind farm in north of Gangan under impact load.](image)
can be subjected to the maximum impact. Load, in the 10s Dunhuang of Gansu (71) node put p=150MW, Q=20Var impact load, while adding gusts to the power supply end wind farm in north of Gangan 40s after the impact load and eliminate gust disturbance. Figure 5, Figure 6 and Figure 7 show the Dunhuang of Gansu 71 substation (impeded load node) under the gust of 13/s, 14m/s, 15m/s, and Lanzhou west of Gansu State (Distance load side); wind farm in north of Gangan (power supply end); voltage change.

Figure 5. Voltage change of Dunhuang of Gansu 71 under impact load and gust disturbance.

It can be seen from Figure 5 that the voltage variation is large when the system is subjected to two kinds of disturbances at the same time. The voltage drop is relatively stable at the gust wind speed of 13m/s and 14m/s. After 35s, the voltage gradually recovers and the disturbance is completely removed. After the voltage is quickly restored to stability. When the gust is 15m/s, there is a large fluctuation when the voltage drops.

Figure 6. Voltage change of Lanzhou west of Gansu 31 under impact load and gust disturbance.

It can be seen from Figure 6 that the voltage fluctuation of Lanzhou west of Gansu at the long-distance load end is much different from that of the impact load only. The voltage gradually rises after the start of the two disturbances, and the voltage gradually decreases at 20s, and the gust is 15m/s. The voltage fluctuation amplitude is large, but the voltage has returned to the voltage value during normal operation when the disturbance is removed.
It can be seen from Figure 7 that the voltage of the north wind farm of Gangan begins to decrease when the gust disturbance is applied at the same time, and the voltage begins to return to stability about 5 seconds before the fault is removed, but when the gust is 15 m/s, the voltage also drops sharply.

Subsequent simulations applied 16 m/s gust disturbances in the same wind field, and the software could not simulate the collapse of the entire grid system.

Conclusion

(1) The Hexi Power Grid with large-scale wind power under the single disturbance of the impact load, the maximum impact load capacity is $P=150\text{MW}$ $Q=20\text{Var}$, the voltage at the long-distance load terminal is basically stable, and the disturbed node and the power terminal recover after the disturbance is eliminated. Normal, the power grid has strong anti-interference ability.

(2) When the system is subject to two internal and external uncertain factors, the voltage fluctuation amplitude is large. When the gust disturbance is 15 m/s under the maximum impact load, the voltage of the disturbed node, the long-distance load end and the power supply terminal are greatly increased. Fluctuations, the system's maximum gust resistance is 16 m/s.

After obtaining the system operation risk assessment indicators, it can be based on this, and it is helpful to study the problems of power grid planning, system maintenance, and reactive power compensation devices in this area, and play an early warning role.

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