Research on Voltage Stability of Large-scale Integration of Wind Power

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ABSTRACT

Large-scale integration of wind power will affect the static voltage stability of the power system. Through the power flow calculation of the regional power grid with wind turbines, the voltage stability of the power grid connected to the wind farm is analyzed based on the P-V curve method. Moreover, the variation of voltage is analyzed by changing the control mode of the fan and adding the reactive power compensator. The results show that the voltage stability of the constant voltage control mode is better than that of the constant power control mode, and the voltage level is obviously improved after adding reactive power compensation.

Keywords: Wind power generation, static voltage stability, P-V curve method, fan control method, reactive power compensation device.

INTRODUCTION

With the substantial increase of wind power grid integration capacity, its complex operation characteristics and modes have brought many new problems to the traditional power grid power flow calculation method, which has significant impact on the stable operation of the power grid and the power supply reliability [1]. The main threat to the voltage stability of wind farms connected to the power grid is manifested in two aspects [2]. On the one hand, the fluctuation and randomness of wind energy causes the output of wind farms to change with time and it is difficult to predict accurately, which leads to the potential safety hazards of wind power generation when it is connected to the power system. On the other hand, the stability of the voltage caused by the high injection power of the wind power in the weak grid is reduced.

In this paper, Power System Analysis Software Package (PSASP) is used to calculate the power flow in a regional power grid. The voltage stability of a large number of wind farms connected to the power grid is analyzed, calculated and simulated. In the case of changing the different operating modes, the corresponding countermeasures are proposed and verified for reference.
STATIC VOLTAGE STABILITY ANALYSIS FOR INTEGRATION OF WIND POWER

Power System Flow Calculation with Wind Farms

The fluctuation of wind power determines the uncertainty of wind farm output power. Large-scale integration of wind power has changed the flow distribution and node voltage level of the system. As the proportion of wind farms in the system power continues to increase, this effect becomes more and more apparent [3]. Therefore, after the wind farm is connected to the power grid, it is very important to analyze the voltage change and reactive power compensation of each node in the system for the safe and stable operation of the power system. The analysis of these problems is based on the power flow calculation.

Power flow calculation is the basis of power system stability analysis [4]. Therefore, it is necessary to reasonably simplify the model of wind farms and properly process the nodes of the wind farms to complete the steady-state power flow calculation of wind farms. At present, the main types of wind turbines used in our country are mainly constant speed asynchronous wind turbines and doubly fed induction wind turbines.

Selection of Wind Farm Node Types

Asynchronous wind turbine is a fixed speed and constant frequency unit. Its speed is essentially constant and reactive power needs to be absorbed from the power system during the operation. The fixed capacitor is usually installed on the wind turbine to compensate for the reactive power demand during the operation of the generator. Compensated generators run near the unit power factor [5]. Therefore, in the process of static voltage stability analysis, such wind farm nodes can be regarded as PQ nodes with certain power factor.

Doubly-fed wind turbine is a variable speed and constant frequency unit. There are two operating modes of doubly fed induction generator, namely, constant power factor and constant voltage mode of operation. The two modes of operation are discussed respectively.

Under the constant voltage operation mode, the doubly-fed generator can absorb or send out the reactive power to maintain the voltage constant. In the range of reactive power regulation of wind turbine, the wind farm can be regarded as a PV node.

Under the constant power factor mode, the power factor of the stator side of the wind turbine can be maintained constant by adjusting the amplitude and phase angle of the external power supply voltage of the rotor winding. If the set value of the power factor of the wind turbine is \( \cos \phi \), then \( Q = P \tan \phi \). The wind farm can be seen as a PQ node.

Voltage Stability

Voltage stability refers to the ability of all the buses in the system to maintain a stable voltage under a given initial operating condition and the power system is disturbed [1]. It relies on the ability to maintain and restore balance between load demand and power supply system. The output power of wind farms is intermittent and random. The output fluctuation of wind farms is similar to the fluctuation of load. The influence on the voltage stability of power grid can be classified into the research scope of static voltage stability.

The wind power plant is regarded as an independent power supply, and a schematic diagram of integration of wind power can be obtained. As shown in Figure 1, Point A represents the point of external wind power plant. \( R_X \) and \( X_X \) are the equivalent resistance and reactance of the transmission line of the wind farm. \( R_W \) and \( X_W \) are the equivalent resistance and reactance of the power grid. \( U_A \), \( U_B \) and \( U_C \) are the voltage of the outlet of the wind
power plant, the voltage of the near substation and the equivalent voltage of the power grid respectively. $P+jQ$ is the power delivered from the wind farm. $P_L+Q_L$ is the substation load near the wind farm [6].

![Figure 1. Schematic Diagram of The Wind farm Connected to The Power Grid.](image)

The relationship between the node voltage of the substation and the voltage of the power grid is as follows:

$$U_B = U_C + \frac{(P-P_L)R_w + (Q-Q_L)X_w}{U_B} + j\frac{(P-P_L)X_w - (Q-Q_L)R_w}{U_B}$$

(1)

For wind farm plants, the large power grid is almost infinite power, that is, the voltage of the power grid remains unchanged. It can be seen from the above formula that the voltage of the substation is related to the size of $P$ and $Q$. When the fluctuation of the wind power output causes the change of $P$ and $Q$, the size of $U_B$ also changes. Therefore, the fluctuation of the active power output of the generator set will inevitably cause the fluctuation of the node voltage of the substation, which brings difficulties to the voltage control of the power grid.

**P-V Curve Method**

P-V curve method is applied to the static voltage stability analysis of integration of wind power [7]. $P$ represents the active power of the entire wind farm. $V$ can be either the terminal voltage of the wind turbine or the voltage at the grid connection. According to the results of the power flow calculation, the P-V curves of different nodes can be drawn [8]. Thus the system bus voltage variation can be monitored. We can do further analysis of the system, including the bus voltage over the limit, voltage fluctuation range, voltage stability and so on.

**IMPACT OF WIND POWER INTEGRATION ON VOLTAGE STABILITY**

**Example Grid Analysis**

The example system used in this paper is a regional power grid with large-scale wind power integration in one province of our country. The system diagram is shown in Figure 2. There is a 330kV substation in this area. Its main transformer capacity is 480MVA. The 330kV side of the substation is connected with the main power grid. The wind turbines in this area are doubly-fed wind generators. Wind farm A is set as the PQ node with the installed capacity of 47.5MW. Wind farm B is set as the PV node and its installed capacity is 50 MW. By changing the output of the two wind farms, we used the PV curve to study the changes of the relevant bus voltages.
Simulation Results

Change the output of the two wind farms, and we can get the simulation results through the software PSASP, the results shown in Figure 3 to Figure 7.

Figure 2. The Simplified diagram of the Example System.

Figure 3. P-V Curve of Bus Node 1.

Figure 4. P-V Curve of Bus Node 2.

Figure 5. P-V Curve of Bus Node 3.

Figure 6. P-V Curve of Bus Node 4.
Figure 7. P-V Curve of Bus Node 5.

From Figure 3 to Figure 7, it can be seen that with the increase of wind farm output, the voltage of grid-connected node 1, node 2 and node 3 of wind farm first increases and then decreases, and the voltage of hub bus node 2 continues to decrease.

As the output of the wind farm increases, the voltage level of the wind farm access point will be improved in the wind farm low output level. This is because the wind power provides part of the active power for the regional grid load and reduces the transmission power from the main grid to the regional power grid, reducing the loss of reactive power lines. Power grid voltage level is improved. When the output of the wind farm is further increased, the wind farm is transformed from the receiving system to the sending system. With the increase of the active power, the reactive power consumption of the transmission line increases. At the same time, as the reactive power demand of the generator increases with the increase of active power, the voltage level of the power grid continues to decrease.

In addition, with the increase of wind farm output, the voltage of node 4 and node 5 shows a decreasing trend. This is because when the wind farm outputs active power to the grid, the long distance line will inevitably consume a part of reactive power and the wind farm itself consumes a large amount of reactive power during power generation, which results in the trend that the bus voltage of the grid is lower than the rated voltage. If you cannot provide enough reactive power support, the regional grid voltage drops, even in severe cases, causing voltage collapse.

STRATEGIES FOR IMPROVING VOLTAGE STABILITY

Change Control Mode of Fan

The control techniques used in wind farms can be divided into constant power factor control and constant voltage control. In the steady state power flow calculation, according to the different control methods, wind turbine is regarded as the PQ node or the PV node [5]. In the above calculation, the wind farm A serves as the PQ node and the wind farm B serves as the PV node. The following will change the control mode of wind farm A. This means that both plants are set up as PV nodes to analyze changes in bus voltage. The voltage variation curve of each bus is shown in Figures 8 to Figure 12.
From Figure 8 to Figure 12, it can be seen that the voltage of node 1, node 2 and node 3 is more stable after changing the control strategy. With the increase of output, the trend of voltage change is more stable. The change of voltage at node 4 and node 5 is not obvious, but the voltage values after changing the strategy are all higher than those before.

4.2 Install Reactive Compensation Device

In the following, a capacitor will be connected in parallel with node 1 to observe the voltage change of each node. The bus node voltage changes as shown in Figure 13 to Figure 17.
From Figure 13 to Figure 17, the safety margin of each bus voltage is increased and the bus voltage level is improved after adding the capacitor reactive power compensation. The reactive power compensation can maintain the voltage of the bus node, which can reduce the voltage fluctuation caused by the power flow variation.

CONCLUSION

After the wind farms are connected to the power grid, the voltage of the regional power
grid will be changed. The voltage of the wind power access point will first increase and then decrease with the increase of output. The voltage at the remaining nodes in the grid decreases with increasing output. When the wind farm adopts the control mode of constant voltage control, the voltage is more stable. The voltage safety margin after compensation will increase. Meanwhile, the corresponding bus voltage level and voltage stability of the power grid will be improved.

REFERENCES