Overview Of Measurement And Evaluation Methods Of Wind Farm And System Inertia Under Large-scale Wind Power Grid Connection

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Abstract: With the large-scale development of new energy, large-scale wind power is incorporated into the power grid, the inertia level of the power system continues to decrease, the system regulation ability continues to weaken, and the system stability is seriously challenged. The evaluation of inertia has become a hot research issue for scholars. Firstly, this paper introduces the basic concept and components of power system inertia. Then, the different methods of inertia measurement and evaluation of wind farm and power system are reviewed. Finally, the future research directions in the field of power system inertia evaluation are summarized.

1.INTRODUCTION

In order to solve the current energy crisis and meet the requirements of sustainable development, the state has strongly supported the development of new energy power generation in recent years. The traditional thermal power generation mode is gradually being replaced and supplemented by new energy power generation such as wind power and photovoltaic. The proportion of new energy power generation in many regions has reached 50% of the total[1].

In order to meet the future energy demand and make wind power better used. In recent years, scholars at home and abroad have done a lot of research on the measurement and evaluation of wind farm inertia and power system inertia. The research on power system inertia mainly includes system identification, inertia evaluation methods based on measured data processing and so on. Reference [2] calculates the inertia of the system by measuring the frequency change of the system and combining the motor rotor
motion equation. However, it is difficult to obtain the initial value of power disturbance and disturbance time accurately. Reference [3] based on the measured data of Iceland, it is proposed that the inertia can be estimated from the environmental measurement data. A method for estimating the effective inertia of power system from ambient frequency and active power is proposed. Reference [4] adopts the sliding window processing method for the frequency and power measurement data, sets the appropriate window length and sliding step, and realizes the online estimation of inertia by using the system equivalent rotor motion equation. For the inertia evaluation of wind farm stations, the main research direction is quantitative evaluation. Reference [5] studies the quantitative analytical characterization method of equivalent virtual inertia of wind farm. Reference [6] analyzes the evaluation method of available virtual inertia of doubly fed fan under all wind conditions by modeling the wind speed of wind farm. Reference [7] establishes a doubly fed wind turbine model with virtual inertia control to calculate the equivalent virtual inertia time constant after wind farm aggregation. Reference [8] established CAR identification model by measuring kilometer increment and frequency deviation of wind farm, and verified the accuracy of the model by comparing the coincidence degree of predicted frequency disturbance and measured frequency disturbance curve of the model.

In view of the above problems. Firstly, this study introduces the definition and composition of power system inertia. Then, the research on the measurement and evaluation of inertia of wind farm and power system at this stage is reviewed, and the existing problems of inertia evaluation at this stage are discussed. This paper summarizes the measurement of wind power grid inertia in China.

2. INERTIA OF POWER SYSTEM

2.1. Definition And Composition Of Inertia

In power system, inertia is defined as the ability of the system to resist energy fluctuation and provide the fastest and most direct response to frequency change. Therefore, maintaining sufficient inertia is of great significance to frequency stability [6]. The traditional inertia is usually composed of grid connected synchronous generator, asynchronous motor and load. In recent years, due to the impact of carbon emission requirements, the power system has gradually turned to new energy such as wind and light. Therefore, at this stage, the inertia of power system is mainly composed of synchronous generator and asynchronous motor.

![Evolution of inertia in modern power system](image)

Figure 1. Evolution of inertia in modern power system

2.2. Traditional Inertia

In traditional inertia, synchronous generator is the main body of inertia. The rotational inertia of the synchronous motor is stored in the rotating rotor and expressed as formula (1):

\[
E_{\text{gen}} = \frac{J\Omega^2}{2}
\]  

(1)

Where: \(E_{\text{gen}}\) is the inertia of the synchronizer; \(J\) is the moment of inertia; \(\Omega\) is the mechanical angular speed of the synchronizer. It can be seen from equation (1) that the rotational inertia provided by the synchronous machine is determined by its own parameters and has nothing to do with its output.

The inertia constant of the synchronous machine is defined as the ratio of the rotating kinetic energy of the synchronous machine rotor to the rated capacity of the synchronous machine at the rated speed, which is formula (2):
Where: $H_{nom}$ is the inertia constant of the synchronizer; $E_{nom}$ is the rotational kinetic energy stored at the rated speed of the synchronous machine; $S_{nom}$ is the rated capacity of the synchronizer; $\Omega_N$ is the rated mechanical speed of the synchronizer.

2.3. Virtual Inertia

The representative of virtual inertia is wind power, photovoltaic and other new energy power generation technologies. According to the control mode of inertia source, it is divided into current source virtual inertia and voltage source virtual inertia.

The current source type virtual inertia is to introduce the frequency change of the system into the active power control link of the converter, change the active power reference of the fan, and make the fan provide the active power proportional to the change rate to the power grid, and the expression is formula (3):

$$\Delta P = K \frac{df}{dt}$$

In the formula: $K$ is the virtual inertia coefficient, which is directly proportional to the rotating inertia of the synchronous machine. The virtual inertia coefficient is not subject to physical constraints and can be set flexibly, but the system requirements and fan working conditions need to be considered. The current source virtual inertia control changes the output power in a short time, improves the unbalanced power of the system, and then reduces the frequency change rate. It does not increase the inertia of the system. It is the power response.

Voltage source virtual inertia mainly refers to virtual synchronous machine technology. Virtual synchronous machine refers to the technology of introducing synchronous machine rotor motion and electromagnetic transient equation into the converter control link to make it have the external characteristics of synchronous machine grid connected operation[9], which can simulate the characteristics of synchronous electromechanical voltage source.

3. Measurement and Evaluation of Wind Farm Equivalent Inertia

3.1. Equivalent Virtual Inertia Estimation Principle

The wind turbine can provide dynamic active power support to the power grid by releasing its own kinetic energy or absorbing the system kinetic energy. Because the wind turbine applies virtual inertia control and the generator speed is coupled with the grid angular speed, according to the definition of virtual inertia of inertia, the virtual inertia of wind turbine can be expressed as formula (4):

$$H_{eq} = \frac{\Delta \omega_0 \omega_0 \omega_{nom} \omega_{nom}}{\Delta \omega \omega_{nom}} H_{DFG}$$

In the formula: $H_{eq}$ is the virtual inertia of the wind turbine, $\omega_0$ is the initial speed of the generator, $\Delta \omega_0$ is the speed increment of the generator, $\omega_{nom}$ is the initial angular frequency of the power grid, $\Delta \omega$ is the angular frequency increment, $\omega_{nom}$ is the rated angular frequency of the wind turbine unit, and $H_{DFG}$ is the natural inertia of the doubly fed wind turbine unit.

When the virtual inertia control strategy is applied to each unit, the whole wind farm will also show the equivalent virtual inertia characteristics, and the equivalent virtual inertia $H_{WF}$ of the wind farm can be used to reflect its inertia response strength. The electromechanical transient characteristics can be expressed by the equivalent rotor motion equation in incremental form, and the time-domain expression can be obtained by Laplace transform (5):

$$g(t) = -\frac{1}{2H_{WF}} \exp(-\frac{D}{2H_{WF}}t)$$

(5)
In the formula: $D$ is the damping coefficient. The equivalent frequency response process of the wind farm can be shown in Figure 2.

![Figure 2. Equivalent frequency response process of wind farm](image_url)

3.2. Measurement And Evaluation Method Of Equivalent Inertia Of Wind Farm

Reference [8] describes the wind farm system by using the controlled autoregressive model by estimating the equivalent virtual inertia of the wind farm as a whole. Because the car model contains unknown parameters, the author uses the time-varying forgetting factor recursive least squares algorithm to further refine the car model. The fast extraction process of virtual inertia needs to determine the model with the lowest order and the highest fitting degree. The final prediction error criterion is selected to carry out the two processes at the same time, which simplifies the complex problem. Finally, the identification parameters are brought into the identification model to compare the coincidence degree between the predicted frequency disturbance curve and the measured frequency disturbance curve. The higher the coincidence degree of the two curves, the higher the accuracy of the identification model. Reference [7] studies the relationship between the equivalent virtual inertia time constant and the dynamic frequency characteristics of power grid. The generator electromechanical transient model, rotor side converter model, virtual inertia controller model and speed controller model are established. Combined with the above models, the doubly fed fan model with virtual inertia control is obtained. The equivalent virtual inertia time constant is calculated by a fan, and the virtual inertia time constant of the whole wind farm is aggregated. Reference [6] combines the air propagation principle, obtains the spatial distribution and time variation characteristics of wind energy in the wind farm by analyzing the wake effect, wind shear effect and time delay effect, constructs the instantaneous wind speed condition probability distribution model under the influence of atmospheric turbulence by using the mixed copula function, and analyzes the operation condition of doubly fed fan under all wind conditions. The rotor speed of the wind turbine is obtained, and the available inertia and the confidence interval of the available inertia of the wind farm are calculated.

4. SYSTEM INERTIA MEASUREMENT AND EVALUATION

4.1. Power System Inertia Response

provides inertia for the system will spontaneously respond to the transformation of system frequency and absorb or release active power to the system. This process is called inertia response. For example, when the system power is unbalanced, the synchronous machine will spontaneously absorb or release the rotational kinetic energy in the rotor, so as to absorb or inject electromagnetic power into the power grid. So as to hinder the frequency fluctuation of the system. The formula can be expressed as (6):
In the formula: $P_e(t)$ is inertia support power; $P_n$ is the rated active power of the synchronizer; $f_n$ is the rated frequency of synchronizer and $f(t)$ is the frequency of synchronizer. Virtual inertia control and energy storage release or absorb energy to the system for a short time according to the control command to provide power support, so as to have the inertia support ability similar to the synchronous machine.

### 4.2. Measurement And Evaluation Method Of System Inertia

Reference [10] considers the physical meaning of inertia in the form of nodes. The relationship among inertia, system inertia and node inertia is considered. It is concluded that in the dynamic process, the support of inertia to frequency is embodied in the blocking effect on the frequency change of each node, which constitutes the blocking effect on the frequency change of the system as a whole. On this basis, it is obtained that the power system inertia has space-time characteristics, that is, the inertia of the same node changes with time, and the inertia of different nodes is different. Reference [11] also considers the frequency distribution characteristics. Firstly, the concept of square deviation of center frequency is defined. Considering the influence of frequency distribution characteristics on inertia evaluation, the concept of inertia graph center is proposed to determine the appropriate frequency acquisition location. The influence of primary frequency modulation on the accuracy of inertia evaluation is reduced. Reference [12], the wind farm and load response are considered, and the virtual inertia control is considered for the wind farm, which is equivalent to a fan. The zip model and zip plus asynchronous motor comprehensive model are compared and analyzed. The change rate of disturbance is obtained. The objective function is established by considering four parameters at the same time. However, the calculation is limited because the power loss of the power grid needs to be considered. Reference [13] studies the method of continuous estimation of grid inertia using active frequency noise disturbance information. By dividing the inertia estimation region, the overall inertia is divided into different parts. Equivalent modeling of power grid. For the small noise disturbance and large noise disturbance of the system, the inertia is estimated respectively.

### 5. Current Development And Prospect

At present, scholars at home and abroad mostly focus on optimizing the frequency modulation control strategy of wind turbine. In contrast, there are relatively few studies on the participation of wind turbines or wind farms in the evaluation of power system frequency modulation service capacity. Whether it is the wind farm evaluation based on the virtual inertia control principle or the evaluation of the available inertia kinetic energy of wind turbine, the virtual inertia of the whole power plant can be estimated. The impact of specific environment on wind power generation is not considered. The impact of shutdown and fault caused by frequency fluctuation on the overall inertia of the wind farm is not considered. An accurate estimate that cannot be made. Therefore, the following research on the inertia of the wind farm should be specific to how to measure the inertia of the current wind farm, how to make different disturbances in the wind farm response system and the evaluation of the wind farm's ability to respond to disturbances. These are specific issues that need to be considered in reality. It is of great help to the current new energy power generation industry.

The proportion of new energy power generation in China is rising, and the current policy still supports new energy power generation. Thirdly, the test of power system becomes extremely arduous. Combined with the current research status, the following suggestions are put forward for the development of inertia control technology in China and the application of inertia demand assessment method in the system. (1) Develop virtual inertia technology for new energy power generation. The frequency security of the system is closely related to the permeability of renewable energy. Under the same power disturbance, the higher the permeability of renewable energy, the greater the frequency fluctuation. Therefore, developing virtual inertia technology for new energy power generation is an effective means to solve this problem.
(2) Put forward the inertia demand evaluation index and standard. At present, there is no definite standard and index for inertia in power system. As a result, the new energy power plant cannot correctly deal with inertia. Corresponding indicators and standards should be proposed from different scales of planning and operation, and the evaluation indicators should be simple and easy to use. At present, there is no clear standard and index for inertia in power system. (3) Improve the on-line monitoring ability of system inertia. On the one hand, improving the inertia monitoring ability can support the formulation of more accurate inertia demand assessment indicators, on the other hand, it can provide guidance for the stable operation of the system. (4) Inertia service marketization. At present, the market operation of inertial service in China is not perfect. In the synchronous machine based power system, inertia has always been used as an "accessory" to provide services free of charge. With the increasing proportion of new energy power generation, the structural contradiction of power supply has become increasingly prominent. The provision of inertial services presents technical and economic differences, that is, it has become a tradable commodity with value differences.

6. CONCLUSION

As the dominant position of asynchronous power supply becomes more and more obvious, the characteristic of "low inertia" of power system will be further highlighted. Starting from the definition and composition of power system inertia, this paper discusses the basic principle of measuring inertia of wind farm. The current methods of measuring wind farm inertia are reviewed. After that, the change of system measurement inertia of wind farm large-scale wind power after connected to the power grid is discussed. Finally, the wind farm and power system are prospected and suggestions are put forward. I hope this paper can provide reference for carrying out relevant work.

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