Research about a fast identification method for intermittent single Sub-synchronous Resonance phenomenon in large scale doubly-fed wind farm

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Abstract. In this paper, a synchronous resonance (SSR) phenomenon caused by a large scale doubly-fed wind farm group after putting in series compensation device is analysed. By analysing the changing trends of the indicators during period of SSR phenomenon, 11 power quality indicators are chosen for calculated, then divided all the 11 indicators into 3 source data and 8 preliminary stage operational data by the observability of value. After divided the two kinds of data, a Pearson correlation coefficient between this two kind data was calculated to judge the relationship of them, and the characteristic indexes with stronger correlation during the resonance period were analysed. The maximum value of the above 8 characteristic indexes in the normal power generation process is used as the basic data for comparison, so as to realize the rapid and accurate judgement of the SSR moment. In the process of SSR judgement, the method has the characteristics of faster speed and simple determination, and it does not need to reform the existing power quality online monitoring device, and can realize real-time analysis and judgement of SSR phenomenon only by increasing extraction of the existing data function from the monitoring system. Finally, by testing data of two actual SSR events, the characteristic index determination method proposed in this paper is analysed and verified, and the feasibility of this method is proved.

1. Introduction

Wind power generation, as an important kind of clean energy power generation has been widely used in the world at present, which is huge especially in the total installed capacity in the northeast areas of China. But wind farms are often located in remote areas, where long-distance transmission lines to reach the center of the load are always needed. Especially when there is some region that is abundant of wind resources, but these area are far away from the large load cities, thus for these wind farm region, there always need long distance transmission lines to transmit electricity to other area[3]. Such as China's Xinjiang, Gansu, northeast China and other wind farm group, this kind of wind farm are using a very long distance 500 kV or higher voltage level transmission lines to transmit electricity for other provinces. In order to increase the transmission capacity of the lines, a fixed series compensation device is generally used in this kind of delivery lines. With the addition of series compensation device, the line reactance can be reduced and the static stability limit of the system can be increased, which can significantly
improve the capacity of wind power transmission\cite{5,7}. However, the addition of series complement devices also brings the risk of sub-synchronous resonance(SSR).

The SSR problem was first discovered in the United States in 1970 and 1971. The Mohave power plant in the United States experienced two resonant accidents, which caused damage to the large shaft of the unit\cite{1}. In October 2009, an SSR accident caused by a series complement capacitor occurred at a wind farm in Texas, USA\cite{2}. In 2012, an SSR accident occurred in a wind farm group in North China, resulting in a large number of wind turbines off-grid. In 2016, a number of sub-synchronous resonance events occurred in Tongyu, Jilin Province, which caused a large number of wind turbine control panels burning, causing a serious impact on the regional power grid\cite{6}. After this, the causes and mechanisms of such SSR phenomena have attracted widespread attention from scholars at home and abroad\cite{4}.

In this paper, the generation mechanism of wind farm SSR phenomenon is firstly summarized. Then, based on the actual parameters and operation mode of various types of wind turbines in a wind farm group in Jilin Province, the multiple resonance phenomenon generated by the wind farm is analyzed. According to the multiple measurement results, several index data during the resonance period are obtained. To realize the rapid judgement of SSR phenomenon, through the application of this method can quickly identify the resonance phenomenon in a short time, at the same time to calculate the characteristic frequency of resonance phenomena. Finally, based on the data of two real SSR cases, the recognition rate and accuracy are verified, and the feasibility of the proposed method is confirmed.

2. An overview of wind farm SSR analysis model and resonance mechanism

Taking a large wind farm group in Jilin Province as an example, there are three wind farms in this region with a total installed capacity of 550MW, which are collected into a 500kV booster station through three 220kV lines, and then transported out through a 500kV line. At the same time, a fixed series compensation device is installed in the 500kV line. As it is shown in Figure 1.

![Fig. 1 Equivalent model of wind farm SSR analysis](image1)

![Fig. 2 Equivalent model of wind farm SSR analysis](image2)
Through the research in recent years, a theory of the mechanism of SSR phenomenon of the wind farm is now widely recognized as the area of wind turbine rotor side converter current monthly coefficient\cite{4,7}, the wind generator series compensation degree of series compensation device, a variety of factors such as grid number, the mutual influence of power grid in the area of the damping coefficient, from positive to negative. There are a total of seven types of doubly-fed units installed in the wind farms in this area, and no direct-drive fans are installed.

As for the SSR phenomenon of wind farms, the main research direction in China is the influence mechanism of various control parameters of the same type of doubly-fed wind turbines on the SSR phenomenon\cite{8}, but how to judge and how to treat the phenomenon has not been thoroughly studied. For example, literature 2,3 mainly studies the influence of various parameters of doubly-fed wind turbine on SSR phenomenon in the state of maximum power tracking. Literature 4,6,7 mainly studies the sequential coefficient of rotor side converters of wind turbine and the influence of the number of wind turbines on resonance phenomenon. The above documents consider all type of doubly-fed wind power unit equivalent for only one type of doubly-fed wind power generator, with series compensation device influence caused SSR phenomenon was studied, without considering the multiple manufacturers of doubly-fed wind power generator on the impact of SSR phenomenon\cite{9,10}, also did not study on SSR phenomenon of rapid identification technology research. It's just an analysis of the available data after the discovery. To the SSR phenomenon in management, the first job is to identification and confirmation of in SSR phenomenon, but the period of SSR time is so short, that the SSR frequency and amplitude of wind farm grid is difficult to be confirmed accurately\cite{2,3}.

3. Analysis of wind farm intermittent single SSR phenomenon

According to the statistics of the multiple SSR phenomena that occurred in the wind farm group, the intermittent single SSR phenomenon is occurring when the B1 and B3 type wind turbines are connecting to the power grid.

In this paper, the data during the normal generation period of the wind farm group without resonance phenomenon is taken as the basic data, and the maximum value of characteristic data during this period is taken as the reference value for determination. Through the analysis of the intermittent single SSR phenomenon, the characteristic values that all change significantly in different SSR processes are confirmed\cite{10}. Three typical criteria are selected from multiple indicators. Once the three index values in the line are found to exceed the reference value, the SSR phenomenon is considered to be going.

3.1. Analysis of intermittent single SSR phenomenon

During the operation of the whole wind farm group, intermittent single SSR phenomenon appears when a particular type of wind turbine connected to the grid. The corresponding waveform of three-phase voltage and three-phase current is shown in Figure 3 to Figure 6. The voltage test points shown in the figure is the current and voltage at the high voltage side of the 220kV main transformer of the wind farm. As it can be seen from Figure 3, in this period, the UA has obvious changed in the intermittent SSR phenomenon, while the UB and the UC have a smaller resonance amplitude. It can be seen from Fig. 4, that obvious amplitude changes occur to the current at the SSR moment.
As can be seen from Fig. 3 and Fig. 4, the resonance phenomenon does not occur continuously all the time, but intermittently. However, the duration of occurrence is not fixed, and the amplitude of voltage change generated at each time of occurrence is also different. During the occurrence of SSR phenomenon, the three-phase voltage fluctuation amplitude is not the same too.

As it is shown in figure 5 and figure 6, in the case of a single intermittent SSR phenomenon, voltage waveform is present in normal fluctuate up and down repeatedly oscillation characteristics of voltage amplitude changes drastically, current waveform on the whole present a fast rising and falling trend, the resonance amplitude change trend during the current and voltage variation trends are similar, are all up and down repeated shock wave.

3.2. Introduction to Pearson correlation coefficients

Pearson correlation coefficient, also known as simple correlation coefficient or linear correlation coefficient, generally expressed by the letter $\gamma$, is used to measure the linear relationship between two variables. When the standard deviation of both variables is not zero, the correlation coefficient is defined.

The index data involved in this paper are all continuous data, and the trend of change is linear in a certain time range, so Pearson correlation coefficient is used as the quantitative analysis method of the
correlation degree among various indicators, and the numerical trend curve of change among various indicators is used as the qualitative analysis method of the correlation degree.

### 3.3. Correlation analysis of each index in intermittent single SSR

A number of data of the above multiple SSR phenomena are extracted, and the index contains 11 power quality indexes data, which are:

1. RMS value of three-phase voltage, \( U (U_A, U_B, U_C) \);
2. RMS value of three-phase current, \( I (I_A, I_B, I_C) \);
3. RMS value of total active power, \( P \);
4. RMS value of \( H_0 \) harmonic voltage inclusion rate, \( U_{H0} (U_{AH0}, U_{BH0}, U_{CH0}) \);
5. RMS value of \( H_0 \) harmonic current containing rate, \( I_{H0} (I_{AH0}, I_{BH0}, I_{CH0}) \);
6. RMS value of zero sequence current value, \( I_0 \);
7. RMS value of negative sequence current value, \( I_2 \);
8. RMS value of the percentage of negative sequence voltage, \( U_2 \);
9. RMS value of percentage of zero-sequence voltage, \( U_0 \);
10. RMS data of total harmonic distortion rate of each phase voltage, \( THD_U (THD_{UA}, THD_{UB}, THD_{UC}) \);
11. RMS data of total harmonic distortion rate of each phase current, \( THD_I (THD_{IA}, THD_{IB}, THD_{IC}) \).

\( U, I \) and \( P \) can be real-time observed of all these 11 indexes, so these three indicators are used as surface of metadata in a correlation analysis, and the rest 8 indicators are used as calculation data index as a preliminary stage, these 8 indexes were calculated by the Pearson correlation coefficient to the previous 3 indicators of relevance.

Correlation analysis is divided into two cases for analysis, which are the normal period of power generation and the SSR phenomenon period of power generation.

### 3.4. Intermittent single SSR judgement method

The index value during the SSR period were recorded, and the maximum value of the three indexes at the normal generating period was taken as the reference value.

According to the period duration of \( H_0 \) harmonics of 0.1s as the judgment period, when the above three index values exceed the max value and the duration exceeds 0.2s, it will be considered a SSR event is occurring. When the three index values are all lower than the max value and the duration exceeds 0.2s, the SSR event is determined to be over.

### 4. Actual case analysis

In order to verify the usability of the above three indexes in the actual SSR phenomenon judgement, the actual SSR phenomenon was analysed. In this paper, two SSR phenomena are selected, the duration of two events are 5.8 seconds and 29 seconds.

#### 4.1. Short time intermittent single SSR judgement example

- Fig. 7 Characterization index curve during SSR (\( U, I, P \))
- Fig. 8 Judgement index curve during SSR (\( THD_I, I_0, I_{H0} \))
As can be seen from Fig. 7, for the SSR event with duration of 5.8 seconds, the fluctuation amplitude of voltage and current is relatively small. The current only changes from 60.7A to 80.6A, and the sudden amplitude is 19.9A, with a percentage of 32.78%. The active power increases from 27000kW to 27612kW, and the abrupt amplitude is 612kW, with a percentage of 2.27%.

4.2. Long time intermittent single SSR judgement example

As can be seen from Fig. 9, for SSR events with duration of 29 seconds, both voltage and current fluctuate in large amplitude. The current changes from 66.5A to 134.8A, with a sudden amplitude of 68.3A and percentage of 102.71%. The active power increases from 25855kW to 27524kW, and the abrupt amplitude is 1669kW, with a percentage of 6.46%. As can be seen from Fig. 10, at the beginning and end nodes of current and voltage mutation, all the three judgement indexes all have significant changes, and the time nodes of occurrence and ending are easy to distinguished.

5. Conclusion

This article analyse an SSR phenomenon caused in a massive doubly-fed generator concentrated interconnection of wind farm, which is using a series compensation device. Pearson correlation method is used for 11 indexes correlation analysis which are chosen from power quality indicators. Then all 11 indicators are divided into 3 basic indexes and 8 calculation indexes, which are divided by source data and the preliminary stage of operation data. According to the maximum value generated by the three indexes during the normal generation period of wind farm, a method to determine the intermittent SSR of large-scale doubly-fed wind turbine is proposed. Finally, the feasibility and rapidity of the proposed method are verified by testing and analysed two different intermittent single resonance cases.

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