Control Strategy of SVG for Sub-synchronous Oscillation of Large-Scale Wind Farms Suppression

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Abstract. In recent years, the installed capacity of wind-driven power is increasing continuously in China, but the main measure for long-distance transmission with wind power integration now is series capacitive compensation due to the inverse distribution of wind energy resources and load center in China. However, similar to the thermal generator set, the sub-synchronous oscillation phenomenon may also occur in the wind generation set when the power is transmitted via the fixed series compensated line or HVDC system.This article will discuss how to suppress similar problems in the large-scale wind farms using SVG according to the experience of some Chinese power plants to suppress the sub-synchronous resonance using SVC and SVG in the past two years.

Introduction

The traditional sub-synchronous oscillation problem has been solved, and a new sub-synchronous oscillation phenomenon called Sub-Synchronous Control Interaction (SSCI) occurred in recent years. This sub-synchronous oscillation problem is the interaction between the converter of wind generating set and the series compensated lines and HVDC system. All the traditional sub-synchronous oscillations are related to the shafting, and they are the mutual motivation under one or several shafting torsional vibration frequencies of the generator set. As SSCI is not related to the shafting torsional vibration frequency of the generator set, and the oscillation frequency depends entirely on the converter control and the structure of electric power transmission system, no fixed oscillation frequency exists. In addition, as it is not related to the mechanical system, its voltage and current oscillation divergence speed is far faster and it is more destructive compared to the traditional sub-synchronous oscillation. In 2009, a wind farm in Texas transmitted the power directly through the series compensated lines due to line breakage, causing rapid divergent oscillation in the port voltage and output current of wind generation set under the sub-synchronous frequency. Many sets tripped and the Crowbar circuits were damaged.

Currently, most researches on the sub-synchronous oscillation problem caused by wind generator are specific to the modeling, calculation and simulation analysis of wind generator itself, the mechanisms of sub-synchronous oscillation caused by wind generator are analyzed very thoroughly, and some suggestions are proposed to suppress the sub-synchronous oscillation starting from the wind generator itself. But an important point is ignored that it is relatively easy to change the control algorithm or strategy of a single wind generator, but it is very difficult to change the algorithm or strategy of large-batch wind generators in an area, and the wind generator supplier of wind farm could hardly develop an scheme to solve the sub-synchronous oscillation problem in the short term. Considering that SVG is installed in all the wind farms to compensate the reactive power and voltage of integration point, a scheme is proposed to solve the sub-synchronous oscillation problem using SVG equipped in the wind farms.

Principle of SVG to Suppress Sub-synchronous Oscillation

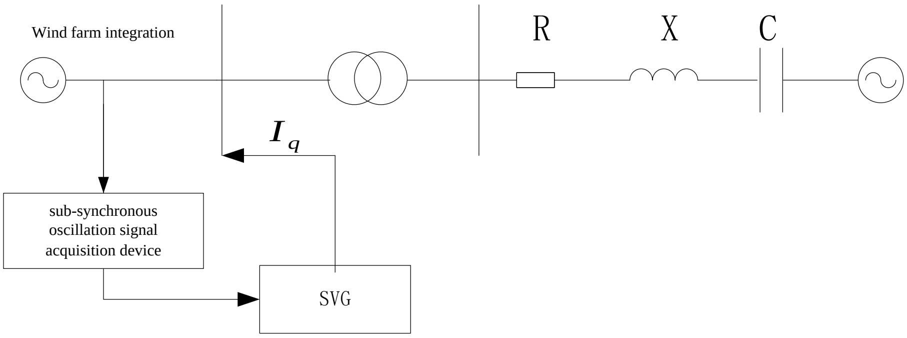

Fig.1. Schematic Diagram of SVG to Suppress Sub-synchronous Oscillation

The sub-synchronous oscillation caused by the large-scale wind farm integration can be suppressed by using the sub-synchronous oscillation signal acquisition device to detect the voltage, current and power signals in the grid-connected system at the access point of wind farm and analyze the characteristic frequency and amplitude of sub-synchronous oscillation, and then outputting the reactive current Iq of any frequency by SVG as required, instead of acquiring the speed signals of generator (wind generator) by convention.

The main difficulty to suppress the sub-synchronous oscillation by SVG is extraction of sub-synchronous oscillation signals. This problem will be analyzed below.

Digital Filter Technology of SVG to Suppress Sub-synchronous Oscillation

Due to wind generator diversity, wind speed, power grid problem and other factors, the modal frequency of sub-synchronous oscillation caused by large-scale wind farm integration is different from the relatively fixed modal frequency of sub-synchronous oscillation caused by the conventional thermal power unit or DC transmission. Its oscillation frequency features diversity and unstability so that the modal signals of sub-synchronous oscillation should be identified quickly and precisely.

To achieve this, first extract the signals using a digital filter which consists of 4 parts: low-pass, high-pass, band-pass and band-stop filters.

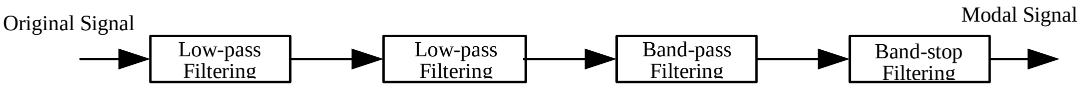

Fig. 2. Schematic Diagram of Modal Frequency Extraction Filter for Sub-synchronous Oscillation

Assume the sub-synchronous oscillation frequency 1 is 15 Hz and the frequency 2 is 22 Hz. According to the experience, if the cut-off frequency of low-pass filter is set to 40 Hz, the cut-off frequency of high-pass filter is set to 10 Hz and the quality parameter of band-pass and band-stop filters is 10, the transfer function of 4 filters is shown below:

$$G_{LPF}(s) = \frac{(40*2\pi)^2}{S^2 + 40*2\pi*S + (40*2\pi)^2} \tag{1}$$

$$G_{HPF}(s) = \frac{(10*2\pi)^2}{S^2 + 10*2\pi*S + (10*2\pi)^2} \tag{2}$$

$$G_{BPF}(s) = \frac{\frac{15*2\pi}{10}S}{S^2 + \frac{15*2\pi}{10}S + (15*2\pi)^2} \tag{3}$$

$$G_{BSF}(s)=\frac{\frac{22*2\pi}{10}S}{S^2+\frac{22*2\pi}{10}S+(22*2\pi)^2} \quad (4)$$

The final filter transfer function is $G_{LPF}(s)G_{HPF}(s)G_{BPF}(s)G_{BSF}(s)$

Of course, only calculating the transfer function of digital filter is far from enough. It should be converted into the actually programmable program codes. The more commonly used method is bilinear transformation. This transformation will compress the entire s plane to a platband (The width is 2π/T, i.e. from -π/T to π/T) in the plane of any medium s_1, and then transform the platband to the entire z plane through the standard transformation relation $z=e^{sT}$ so that there is a one-to-one corresponding relation between s plane and z plane. Using this transformation, the difference equation of filter transfer function can be calculated and converted into the program codes finally. The required modal characteristic quantity is calculated by the controller in real time.

Phase Compensation Technology of SVG to Suppress Sub-synchronous Oscillation

After extraction of modal characteristic quantity, the phase compensation is also required. According to the characteristics to be compensated measured on site, the phases near the resonance point jump, and it is difficult to properly compensate the phases in the range of all the sub-synchronous frequencies. Therefore, only the phases near the sub-synchronous resonance point will be compensated. The time parameter of compensating link is determined using the lead-lag link in the form of $\frac{1+sTa}{1+sTb}$ and the formula (5).

$$a=\frac{T_b}{T_a}=\frac{1-\sin\phi}{1+\sin\phi} \quad (5)$$

In which: $T_a=1/(\omega_x\sqrt{a})$; $T_b=aT_a$. ωx is the frequency of selected phase compensation, Φ is the lagging phase angle to be compensated corresponding to ωx, and Ta and Tb is the time constant of compensating link. First calculate the time parameter of compensating link roughly and then perform optimization and correction on site to obtain the optimum parameter and achieve the best compensation effect.

Control Strategy of SVG to Suppress Sub-synchronous Oscillation

As such sub-synchronous oscillation often occurs at the moment of wind farm integration, the main control strategy of original SVG remains unchanged while only the sub-synchronous frequency detection of power grid voltage and current is added in the original control strategy, and the sub-synchronous oscillation will be suppressed once found.

As the actual field systems contain several components of sub-synchronous oscillation frequency, the sub-synchronous oscillation suppression strategy should perform weighted stacking for the corresponding multiple links to form a modulating signal containing multiple sub-synchronous oscillation suppression frequencies. This signal will be stacked onto the fundamental wave debugging signal required by the constant voltage control link of SVG to form the final modulating signal, so that the current output by SVG contains not only the fundamental current required by the voltage or reactive power control, but also the current required to suppress the field sub-synchronous oscillation.

Field Test of SVG to Suppress Sub-synchronous Oscillation

In Santanghu, Hami, Xinjiang, there are two 220kV wind power collection stations which share a segment of 220kV power transmission line connected to the 750kV Hami substation via Shanbei substation. The wind farms have high capacity and are equipped with the direct-drive and double-fed wind generators supplied by numerous manufacturers, and the Phase Ⅱ and Ⅲ expansion plans are carried out orderly. This region features the centralized grid connection of large-scale wind generators and long-distance AC transmission. Through simulation analysis and field test, the relevant experts from State Grid Electric Power Research Institute and Xinjiang Electric Power Research Institute confirm that several sub-synchronous oscillation accidents have occurred in this region due to large-scale wind generator integration. As the SVG device has been installed in all the wind farms of this region, all the original control programs should be upgraded to the new program with a function to suppress sub-synchronous oscillation.

First test the characteristic frequency of sub-synchronous oscillation in the wind generators of this region under various working conditions, such as full load with high wind, almost empty load with extreme breeze, 30% full load, 50% full load and 80% full load, and then verify the suppression effect under the characteristic frequency. The test result shows:

1. Under almost empty load with extreme breeze, the characteristic frequency is very complex and unstable, and appears as a frequency band.
2. Under most working conditions with load less than 80%, the sub-synchronous oscillation often occurs with relatively fixed frequency and can be easily controlled.
3. Under heavy load, the system is relatively stable with almost no sub-synchronous oscillation.

For the above analysis results, select the suppression effects and characteristic frequencies under the representative working conditions and frequencies for description.

Light-load working condition

When the active power of 220kV main transformer of Tianshan Electric Power is lower than 2MVA, the sub-synchronous oscillation occurs. Figure 3 is the FFT analysis of power grid voltage and SVG current.

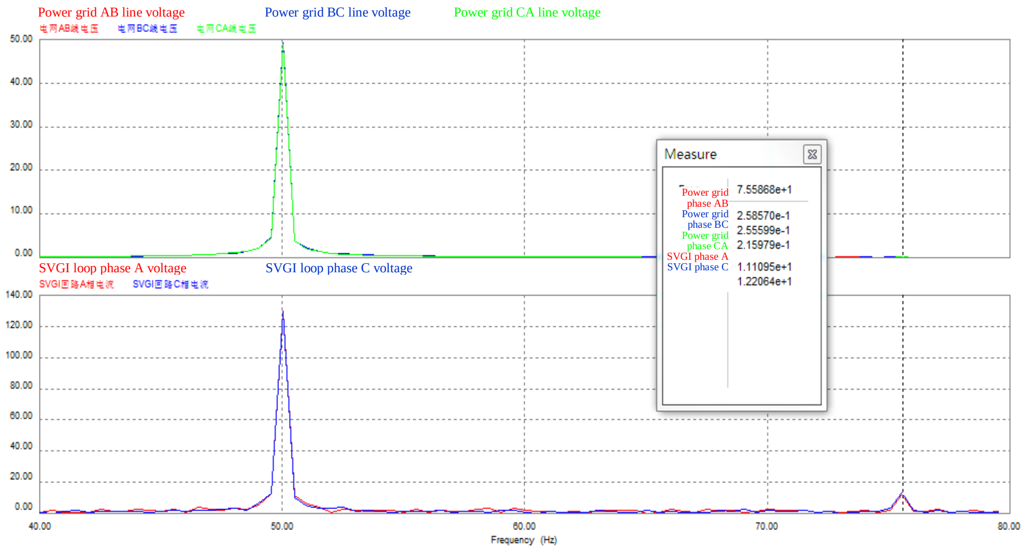

Fig. 3. FFT Analysis of Power Grid Voltage and SVG Current under Light-load Working Condition

The analysis result shows: The characteristic frequency of sub-synchronous oscillation is 75.5Hz under the working condition. After the suppression function is added in SVG, the SVG current contains 75.5Hz current component obviously while the power grid voltage has no 75.5Hz voltage component at this time. This proves that SVG has good suppression effect.

Non-light load working condition

When the active power of 220kV main transformer of Tianshan Electric Power is lower than 50MVA, the sub-synchronous oscillation occurs.

The analysis result shows: The characteristic frequencies of sub-synchronous oscillation are 22.5Hz and 77.5Hz under the working condition. After the suppression function is added in SVG, the SVG current contains 22.5Hz and 77.5Hz current components obviously while the power grid voltage has no corresponding voltage components at this time. This proves that SVG has good suppression effect.

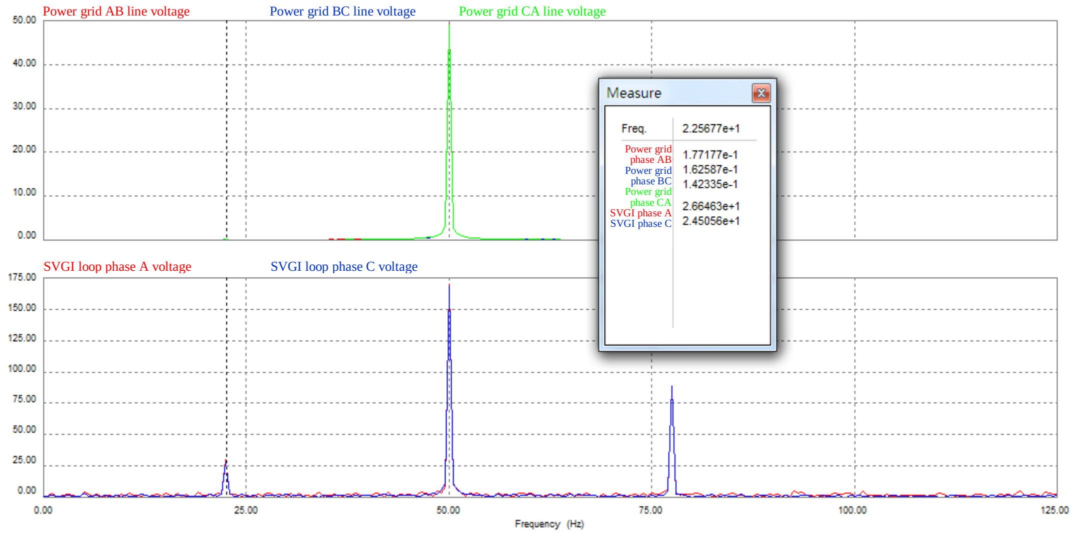

Fig.4. FFT Analysis of Power Grid Voltage and SVG Current under Non-light Load Working Condition

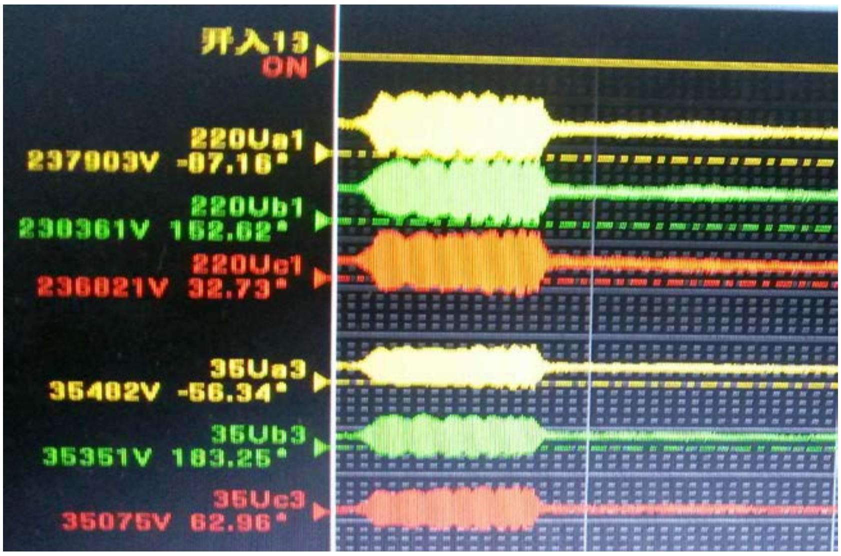

Fig.5. 220kV and 35kV Power Grid Voltage Amplitude Fluctuation Curve

Figure 5 shows that 220kV and 35kV power grid voltage oscillation amplitude decreases obviously when the sub-synchronous oscillation occurs in the system after the function to suppress the sub-synchronous oscillation is added in SVG. This proves that the suppression function is valid.

Conclusion

Through simulation and analysis, the scholars at home and abroad found that the large-scale wind generator integration will cause the sub-synchronous oscillation problem, especially in some remote regions and at the transmission ends, and proposed to use the control system of wind generating set to solve the sub-synchronous oscillation problem. However, the actual project usually includes several wind farms and each wind farm has products produced by several wind generating set manufacturers. Therefore, the lack of uniform control index or algorithm and strategy constraints between different control strategies from several manufacturers will cause the problem to be more complex.

Based on the above difficulties, this article proposes a method to use the SVG installed in the wind farm to suppress the sub-synchronous oscillation caused by the wind generator integration, and proves that the method is valid and stable through simulation research, field test and practice. This method will inevitably become the most advantageous, economical and intuitive means popularized by the industry in the future as the on-site sub-synchronous oscillation problem can be solved only by changing and optimizing the existing control software in SVG without investing the hardware devices.

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