Suppression Methods for Low Frequency Oscillation of Wind Farm Considering SVG Minimum Output Dead Zone

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Abstract. At present, the research of Static Var Generator (SVG) mainly focuses on the main circuit topology, the optimization of control strategy, the method of selection, and lack of research on the low frequency oscillation of the wind farm caused by SVG minimum reactive output dead zone in practical engineering applications. For this reason, this paper first studies the mechanism of the low frequency oscillation of the wind electric field induced by the SVG minimum output dead zone of the wind farm, and discusses the conditions of this type of oscillation. On this basis, the automatic voltage control system (AVC) optimization model of wind farm is established with the minimum reactive variation of SVG output near the zero point as the optimization goal, and an optimization control strategy of wind farm with SVG minimum output reactive dead zone is proposed. Finally, the correctness of the result is verified by simulation. The results show that, due to the existence of the minimum output dead zone in the wind farm, the large reactive step may occur near the zero point of the SVG output, which causes the voltage low frequency oscillation of the wind farm. The optimization strategy proposed in this paper can significantly suppress the low frequency oscillation by coordinating and optimizing reactive power output near the zero point of multiple SVGs in wind farm.

1. Introduction

Wind power has the characteristics of random fluctuation and access to the end of power grid, which has an increasingly prominent impact on power quality and voltage stability of power system. SVG is an important measure to improve the power quality of the wind farm and improve the stability of the power system. It has been widely used in the wind farm. At present, the reactive power equipment such as SVG, wind turbine and capacitor in wind farms are generally controlled by the wind farm automatic voltage control system (AVC), in order to ensure the voltage stability of wind farm.

In the existing literature, the optimization of SVG control strategy [1]-[5], the influence of SVG on the voltage stability of the power system [6]-[7], and the reactive power coordination strategy of SVG and wind turbine [8]-[11] are studied in a large amount. In [3], a SVG optimization control strategy under unbalanced voltage is proposed. The effect of reactive power compensator’s position to the synchronous oscillation is studied in [6], and a PID control based on phase compensation method is proposed to suppress subsynchronous oscillations. In [10], a set of two stage voltage control systems considering the fast dynamic reactive power compensator is proposed, which take advantage of SVG in steady voltage control and transient voltage stability. However, in the actual application, SVG usually sets the minimum output dead zone. If the wind farm AVC strategy does not consider the
influence of this factor, it may lead to the voltage low frequency oscillation near the zero point of SVG reactive power output, which has not yet been studied in the literature. In this paper, the mechanism of the low frequency oscillation of the wind electric field induced by the SVG minimum output dead zone of the wind farm is studied first, and the conditions of this type of oscillation is discussed. On this basis, the automatic voltage control system (AVC) optimization model of wind farm is established with the minimum reactive variation of SVG output near the zero point as the optimization goal, and an optimization control strategy of wind farm with SVG minimum output reactive dead zone is proposed. Finally, the correctness of the result is verified by simulation

2. Mechanism of low frequency oscillation
An actual wind farm contains two 7.5Mvar SVG, and the reactive dead zone of each SVG is 0.85Mvar. AVC regulation period of the wind farm is 60s, the voltage dead zone is 0.3kV. The phenomenon of low voltage oscillation occurs during the operation of wind farm, as shown in the figure 1. The voltage and reactive power of the wind farm during the period of t₁-t₂ are shown in Table 1.

![Figure 1. Low frequency oscillation of an actual wind farm.](image)

Table 1. Wind farm values during t₁ and t₂

| Time     | Voltage | 1#SVG | 2#SVG |
|----------|---------|-------|-------|
|          | Instruction value (kV) | Actual value (kV) | Instruction value (Mvar) | Actual value (Mvar) | Instruction value (Mvar) | Actual value (Mvar) |
| t₁       | 113     | 113.38 | 0.33  | 0.85  | 0.33  | 0.85  |
| t₁+T     | 113     | 112.60 | -0.3  | -0.85 | -0.3  | -0.85 |
| t₁+2T    | 113     | 113.36 | 0.33  | 0.85  | 0.33  | 0.85  |
| t₁+3T    | 113     | 112.68 | 0.41  | 0.85  | 0.41  | 0.85  |

It is known that when the AVC voltage instruction value of the wind farm is 113kV, the demand reactive power of the wind farm is calculated by the AVC strategy. The reactive power instructions issued to each SVG is 0.33Mvar at t₁ moment, but the actual output reactive power of each SVG is 0.85Mvar because of the existence of output dead zone. At this time, the actual voltage of the grid is
113.38kV, which beyond the upper limit of the AVC voltage dead zone, so the AVC continue to calculate and modulate. Similarly, the calculated reactive power instruction of each SVG is -0.3Mvar at t1+T moment, but the actual output reactive power of each SVG is -0.85Mvar. The actual voltage of the node is 112.6kV at t1+T moment, which beyond the low limit of the AVC voltage dead zone, so the AVC continue to calculate and modulate. The output reactive power of each SVG changes step by step between 0.85Mvar and -0.85Mvar, and the voltage of the wind farm oscillates between 112.6kV and 113.38kV.

It can be seen that when the voltage of the wind farm is adjusted to near the output zero point of SVG, due to the existence of the minimum output reactive dead zone of SVG in the wind farm, the output reactive power of the SVG may have great step change near zero point, resulting in the repeated regulation of the voltage because of exceeding the voltage dead zone of AVC. Besides, the oscillation period is two times that of the AVC regulation period.

3. Generating conditions of oscillation
The low frequency oscillation of this type of wind farm requires the following conditions:
(1) There is reactive output minimum dead zone in SVG in wind farms.
(2) The wind farm is connected to the weak power grid, that is, the short circuit capacity of the wind farm is small.
(3) The voltage variation caused by the step of SVG dead time is greater than 2 times of the dead time of AVC voltage, that is

\[ \Delta U > 2U_d \]  

Where

\[ \Delta U = \frac{\Delta Q}{S} \]  

(4) The AVC voltage instructions issued to SVG is near the zero point, and satisfy:

\[ U_{ref} - U_{min} > U_d \]
\[ U_{max} - U_{ref} > U_d \]

4. Oscillation suppression method
This paper propose a method to suppress the low-frequency oscillation near zero point considering the dead zone of SVG, as follows:
(1) Suppose the wind farm has a number of n SVG, each SVG output reactive power dead zone is from small to large: \( Q_{1d} \leq Q_{2d} \leq \cdots \leq Q_{nd} \), that is

\[ Q_{id} \leq Q_{jd} \leq L \leq Q_{nd} \]  

(4)

Define variables:

\[
\begin{align*}
Q &= Q_{id} + Q_{jd} + L + Q_{nd} \\
Q_2 &= -Q_{id} + Q_{jd} + L + Q_{nd} \\
Q_{ref} &= -Q_{id} - Q_{jd} - L - Q_{nd}
\end{align*}
\]  

(5)

(2) Suppose that according to the AVC voltage command, the total reactive power of SVG needs to be \( Q_{avg} \), and satisfied.

\[ \frac{Q + Q_{id}}{2} < Q_{avg} < \frac{Q + Q_{jd}}{2} \quad (1 \leq i \leq n+1) \]  

(6)

(3) The optimal total reactive power for SVG is \( Q_0 \), that is, the reactive power instructions to SVGs are \([-Q_{id}; -Q_{jd}; \ldots; -Q_{(i-1)d}; Q_{id}; Q_{jd}; Q_{(i+1)d}; \ldots; Q_{nd}]\), at this point, SVG has the smallest step of reactive power near zero point.

5. Simulation result
A wind farm model is built in Matlab, the wind farm contains three 6Mvar SVG, and the reactive dead zone of each SVG is 0.6Mvar. AVC regulation period of the wind farm is 30s, the voltage dead zone is 0.2kV. The simulation waveforms before and after the suppression method adopted are shown in Figure 2~ Figure 3, and the variable values during the time between 2.5min and 4min are shown in Table 2.

It can be seen from Figure 2 that before the optimization method adopted, when the AVC instruction voltage is leaped from 112kV to 113.15kV, the calculated SVG reactive instruction is near the zero point. Thus, the output reactive power of each SVG is simultaneously step changed between -0.6Mvar and 0.6Mvar, resulting in the grid voltage continue beyond the AVC voltage dead zone and oscillates in low frequency, the oscillation period is 1 min, as shown in Figure 2.

After the optimization method described in this paper adopted, the reactive power instructions of each SVG are -0.6Mvar, 0.6Mvar, 0.6Mvar, and the actual grid voltage is 113.24kV at this time. It can be seen that the low frequency oscillation of voltage is disappeared, as shown in Figure 3, which proves the correctness of the method described in this paper.

**Figure 2.** Voltage step waveform before optimization methods adopted.

**Figure 3.** Voltage step waveform after optimization methods adopted.
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Table 2. Wind farm values during 2.5–4min

| Time (min) | Voltage Instruction value (kV) | Voltage actual value (kV) | 1#SVG value (Mvar) | 2#SVG value (Mvar) | 3#SVG value (Mvar) | SVG total value (Mvar) | State |
|------------|--------------------------------|---------------------------|------------------|------------------|------------------|---------------------|-------|
| before optimization | 2.5~3 | 113.15 | 113.43 | 0.6 | 0.6 | 0.6 | 1.8 | low |
| | 3~3.5 | 113.15 | 112.85 | -0.6 | -0.6 | -0.6 | -1.8 | frequency oscillation |
| | 3.5~4 | 113.15 | 113.43 | 0.6 | 0.6 | 0.6 | 1.8 | |
| after optimization | 2.5~3 | 113.15 | 113.24 | -0.6 | 0.6 | 0.6 | 0.6 | no oscillation |
| | 3~3.5 | 113.15 | 113.24 | -0.6 | 0.6 | 0.6 | 0.6 | |
| | 3.5~4 | 113.15 | 113.24 | -0.6 | 0.6 | 0.6 | 0.6 | |

6. Conclusion
In this paper, the mechanism and production conditions of the low frequency oscillation of wind farm caused by the SVG minimum output dead zone are studied. On this basis, an optimization model for the minimum reactive variation near the zero point of SVG is established, and an optimization suppression strategy is put forward, and the simulation verifications are carried out at the end of the simulation. The main conclusions are as follows:

1. Due to the existence of the minimum output reactive dead zone of SVG in the wind farm, the output reactive power of the SVG may have great step change near zero point, resulting in the repeated regulation of the voltage because of exceeding the voltage dead zone of AVC. Besides, the oscillation period is two times that of the AVC regulation period.

2. The proposed AVC optimization strategy, which considers the SVG minimum output reactive dead zone, can reduce the step reactive power variation by coordinating the reactive power output of SVGs near the zero points, and can significantly suppress this low frequency oscillation of the wind farm.

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