Optimization Analysis of AVC Adjustment Strategy for Power System with Large-scale Wind Power

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Abstract: As a kind of economical and clean renewable energy, wind power generation is more and more widely used. Wind power plants are far away from the load center and the output power is highly random. Therefore, the control of reactive power, voltage and network loss at public connection points are more difficult. The automatic voltage control system uses the real-time operating data of the power grid to select the best reactive voltage control scheme from the perspective of the entire system. It takes the voltage safety and quality as the conditional limit, takes the economy of the system as the goal, and optimizes the voltage in real-time control. This article gives a control strategy for the problem of inability to smooth transition and repeated oscillations in the signal processing of the abnormal state of the AVC system. The upper and lower limit planes of voltage and reactive power are divided into 27 areas, and each area corresponds to different control strategies. This method can be used to achieve smooth transition of control strategy, real-time voltage optimization control.

1. Introduction
Automatic voltage control (AVC) is one of the two automatic control systems (AGC, AVC) of modern power grids. It has the functions of improving the voltage quality of the power grid, reducing the power loss, increasing the stability reserve and reducing the labor intensity of the dispatchers on duty, and it can ensure the safety of the power grid. Economic and high-quality operation [1-3]. Automatic voltage control refers to the centralized monitoring, analysis and calculation of the reactive voltage status of the entire grid, and coordinated and optimized control of the widely dispersed grid reactive power devices from a global perspective [4]. Automatic voltage control can not only realize the automatic adjustment of reactive voltage, but also has a certain optimization function. It is an important technical means to maintain system voltage stability, improve grid voltage quality and the economic operation level of the entire system, and improve the level of reactive voltage management [5-7].

At present, there is a major problem in the operation of AVC. The normal and abnormal state of AVC is handled using existing strategies, and the problem of AVC's inability to smooth transition and repeated oscillations will appear. This paper adopts the method of joint optimization strategy, dividing the voltage-reactive power plane into 27 areas by dividing the upper and lower limits of the voltage and the power factor of the inlet end of the substation into 27 areas, and each area corresponds to a different control strategy. In actual operation, the system will obtain real-time voltage and reactive power data to obtain control methods in different areas according to the adjustment criteria. By adjusting the on-load
transformer tap position and the switching state of the parallel capacitor bank, maintain voltage qualified and reactive power balance.

2. The specific strategy design adopted by AVC

At present, there is a major problem in the operation of AVC, that is the switching strategy of AVC cannot be smoothly transitioned under normal and abnormal states and different abnormal states, and repeated oscillations occur. Analysis of abnormal conditions of the power plant includes:

(1) The bus voltage limit of the power plant is divided into three situations: the upper limit, the lower limit, and the limit is not exceeded.

(2) The reactive power limit of the generator set is divided into three situations: the upper limit is exceeded, the lower limit is exceeded, and the limit is not exceeded.

(3) The AVC sub-station of the power plant sends an excitation blocking signal to the main station, which can be divided into three situations: upper-locking, lower-locking, and non-locking.

Due to the difference in voltage limit signal, reactive power limit signal and blocking signal, AVC is divided into 27 different operating states. Corresponding to each operating state AVC needs to adopt a different pressure regulation strategy. These strategies switch repeatedly along with the transition of states, and all possible strategy switching should be smoothly transitioned. In order to achieve a smooth transition, this article gives the following implementations.

![Figure 1. AVC voltage control strategy adjustment method](image)

This embodiment will be described in detail with reference to FIG. 1. An AVC voltage control strategy adjustment method described in this embodiment includes the following steps:

Step 1: When there is an abnormality in the power grid, determine the type of abnormality. When the abnormal type is only reactive power over-limit, perform reactive power correction on the AVC voltage; when the abnormal type is only voltage over-limit, perform voltage correction on the AVC voltage; when the abnormal type is only the excitation is blocked, keep the current control strategy unchanged; when the abnormal type is reactive power over-limit and voltage over-limit, perform step 2;
when the abnormal type is reactive power over-limit and excitation blocking, perform step 3; when the abnormal type is For voltage limit violation and excitation blocking, perform step 4; when the abnormal type is reactive power limit violation, voltage limit violation and excitation blocking, perform step five;

Step 2: Determine whether the directions of reactive power over-limit and voltage over-limit are the same, if yes, go to step 7; otherwise, go to step 8;

Step 3: Determine whether the reactive power overrun and the excitation blocking direction are consistent, if yes, perform reactive power correction on the AVC voltage, otherwise go to step 9;

Step 4: Determine whether the voltage limit is the same as the excitation blocking direction, if yes, perform voltage correction on the AVC voltage, otherwise proceed to step 9;

Step 5: Determine whether the directions of reactive power over-limit and voltage over-limit are the same, if yes, go to step 6; otherwise, go to step 9;

Step 6: Determine whether the reactive power overrun and the excitation blocking direction are consistent, if yes, go to step 7, otherwise go to step 9;

Step 7: Calculate the command voltage change during reactive power correction and the command voltage change during voltage correction respectively, and correct the AVC voltage in a way that the command voltage changes greatly;

Step 8: Use reactive power correction and voltage correction to correct the AVC voltage together;

Step 9: Exit the current control and send an alarm signal to the upper computer.

2.1. Reactive power correction of AVC voltage

Extract the unit with the largest reactive power limit in the power grid, and record the reactive power limit of the unit as $\delta_q$. When the current reactive power limit of the grid is greater than the allowable upper limit, the correction value of the command voltage is $0.02\delta_q$. Correct the decrease of the current command voltage of the grid is $0.02\delta_q$; When the current reactive power limit of the grid is less than the allowable lower limit, the correction value of the command voltage is $0.04\delta_q$, Correct the increase in the current command voltage of the grid is $0.04\delta_q$. Specifically, when the generator generates more reactive power by 10Mvar, the command voltage is reduced by 0.2kV. That is to say, when the voltage is stable and the unit is steadily generating 10Mvar reactive power, the command voltage is increased by 0.2kV, and the voltage correction command caused by over-limit reactive power is reduced by 0.2kV, so that the final command is to maintain the current voltage and the system reaches stability. At the same time, when the generator generates less reactive power by 5Mvar, the command will increase by 0.2kV over the optimized voltage.

2.2. Voltage correction of AVC voltage

The voltage command correction (voltage correction) for the power plant bus voltage exceeding the limit, the reference voltage exceeding the limit, is proportionally converted into the reverse correction value of the voltage command. This correction value is a piecewise function, because the maximum correction value is limited by the AVC command step length and should not be too large. At the same time, if the optimized voltage itself can be more conducive to removing the voltage limit, the optimized voltage should be used.

Record the actual busbar voltage of the current power plant as $V_{now}$, the upper limit of voltage as $V_{max}$, and the lower limit of voltage as, then the upper $\delta_{v1}$ and lower $\delta_{v2}$ correction values of the command voltage are:

$$\delta_{v1} = V_{now} + 1.5 - V_{max};$$
$$\delta_{v2} = V_{now} - 1.5 - V_{min};$$

When $\delta_{v1} < 1.5kV, V_{now} - \delta_{v1}/3 - 0.1$ will be the current command voltage of the grid;

When $\delta_{v1} \geq 1.5kV, V_{now} - 0.6$ will be the current command voltage of the grid;
When \( \delta_{V} < 1.5kV \), \( V_{now} + \frac{\delta_{V}}{3} + 0.1 \) will be the current command voltage of the grid;

When \( \delta_{V} \geq 1.5kV \), \( V_{now} + 0.6 \) will be the current command voltage of the grid.

Specifically, the upper limit of the voltage is 239kV. According to the calculation rules of the AVC main program, the optimized voltage will not exceed 237.5kV. If the optimized voltage is fixed at 237.5kV and the actual voltage is 237.5kV, the command voltage will be 237.4kV; if the actual voltage is 238kV. The command voltage will be 237.73kV; if the actual voltage is 238.5kV, the command voltage will be 238.07kV; if the actual voltage is 239kV, the command voltage will be 238.4kV; if the actual voltage is 239.5kV, the command voltage will be 238.9kV.

**3. Specific strategies and recommendations adopted by AVC**

In order to express the relationship between the AVC state conversion, and formulate strategies for different operating states, in Figure 2, the nodes represent the possible operating states of the AVC, and the ridge connecting the two vertices indicates that the two states can be converted due to a single signal change. Considering that the actual operating state of AVC can basically only change due to the change of a single signal. Therefore, special attention should be paid to checking the stability of the system during strategy switching caused by possible state transitions, to prevent repeated state switching caused by the implementation of different strategies, resulting in system voltage oscillations.

![Figure 2. AVC system state transition diagram](image)

In each state where abnormal signals occur, the AVC strategy may need to be changed, but it may also be the same. Therefore, under the 27 different states of AVC, the AVC adjustment strategy adopted is limited. In order to express the relationship between the AVC status and the mutual transformation, strategies are formulated for different operating statuses. As shown in Figure 2, the nodes in the figure represent the possible operating states of the AVC, and the ridge connecting the two vertices indicates that the two states can be switched due to the change of a single signal. The top surface of the cube in Figure 2 represents the upper limit of the voltage, the bottom surface represents the lower limit of the voltage, the front represents the magnetization lockout, the back represents the demagnetization lockout, the left represents the lower limit of reactive power, and the right represents the upper limit of reactive power.

AVC recommended strategies and currently implemented strategies are shown in Table 1. The state numbers in Table 1 correspond to the node numbers in Figure 2:

| Status | Voltage | Reactive | Atresia | Suggested Strategy |
|--------|---------|----------|---------|-------------------|
| 1      | Upper limit | Upper limit | Upper atresia | Take the maximum amount of adjustment in the reactive voltage correction |
| Step | Limit 1          | Limit 2          | Limit 3          | Action                                                                 |
|------|-----------------|-----------------|-----------------|----------------------------------------------------------------------|
| 2    | Upper limit     | Upper limit     | Down atresia    | Exit and alert                                                        |
| 3    | Upper limit     | Upper limit     | No atresia      | Take the maximum amount of adjustment in the reactive voltage correction |
| 4    | Upper limit     | Lower limit     | Upper atresia   | Exit and alert                                                        |
| 5    | Upper limit     | Lower limit     | Down atresia    | Exit and alert                                                        |
| 6    | Upper limit     | Lower limit     | No atresia      | After voltage correction + reactive power correction component       |
| 7    | Upper limit     | No limit        | Upper atresia   | Voltage correction                                                    |
| 8    | Upper limit     | No limit        | Down atresia    | Exit and alert                                                        |
| 9    | Upper limit     | No limit        | No atresia      | Voltage correction                                                    |
| 10   | Lower limit     | Upper limit     | Upper atresia   | Exit and alert                                                        |
| 11   | Lower limit     | Upper limit     | Down atresia    | Exit and alert                                                        |
| 12   | Lower limit     | Upper limit     | No atresia      | After voltage correction + reactive power correction component       |
| 13   | Lower limit     | Lower limit     | Upper atresia   | Exit and alert                                                        |
| 14   | Lower limit     | Lower limit     | Down atresia    | Take the maximum amount of adjustment in the reactive voltage correction |
| 15   | Lower limit     | Lower limit     | No atresia      | Take the maximum amount of adjustment in the reactive voltage correction |
| 16   | Lower limit     | No limit        | Upper atresia   | Exit and alert                                                        |
| 17   | Lower limit     | No limit        | Down atresia    | Voltage correction                                                    |
| 18   | Lower limit     | No limit        | No atresia      | Voltage correction                                                    |
| 19   | No limit        | Upper limit     | Upper atresia   | Reactive power correction                                             |
| 20   | No limit        | Upper limit     | Down atresia    | Exit and alert                                                        |
| 21   | No limit        | Upper limit     | No atresia      | Reactive power correction                                             |
| 22   | No limit        | Lower limit     | Upper atresia   | Exit and alert                                                        |
| 23   | No limit        | Lower limit     | Down atresia    | Reactive power correction                                             |
| 24   | No limit        | Lower limit     | No atresia      | Reactive power correction                                             |
| 25   | No limit        | No limit        | Upper atresia   | Keep current                                                          |
In order to study and verify the stability of system operation when switching between strategies, corresponding to the strategies in Table 1, analyze Figure 2.

Figure 2 has 54 short ridges, which are 54 conversion relationships. Divided into three situations:

1. The 6 edges connecting the center of the cube body (indicated by a four-pointed star) and the center of the face: representing the conversion relationship between the 6 single abnormal signal states 9, 18, 21, 24, 25, 26 and the normal state 27.

2. The 24 edges connected between the face center and the edge center of the cube: represent the conversion relationship between 6 single abnormal signal states and 12 double abnormal signal states.

3. The 24 edges connecting the center of the cube and the vertex angle: represent the conversion relationship between 12 double abnormal signal states and 8 three abnormal signal states.

4. The operational effect of AVC’s strategy

4.1. The first category

The No.9 state is voltage corrected, \( V_{new} = \frac{\delta_{V}}{3} - 0.1 \) or the smaller value of the optimized voltage is used as the command voltage to issue. For example, if the optimized voltage is too high, the execution of the command will cause the command \( \delta_{V_1} = V_{new} + 1.5 - V_{max} \) to continue to approach 0, and the command value will continue to 237.4 kV is close. If it enters below 237.5kV, the system is in a normal state, and the optimized voltage (237.5kV) is directly issued in the normal state, and all command voltages will be stable between 237.4kV and 237.5kV. If the optimized voltage drops (237kV), the command will be issued 237V, and the system will smoothly transition to the normal state without repetition. The same is true for the 18th state. Reactive power correction in state 21. If the optimized voltage command is to increase by 0.2kV, the unit will send 10Mvar more reactive power than the upper limit value. The voltage correction command caused by reactive power exceeding the limit is reduced by 0.2kV, so the final command is maintained. At the current voltage, the system has stabilized. When the optimized voltage command is reduced, the system smoothly goes to the normal state. The same is true for the 24th state, but the value of reactive power loss is reduced by half. The current state is maintained in the 25th state. If the optimized voltage is too high, the voltage command will be maintained and the state will not change. If the optimized voltage is low, it will smoothly transition to the normal state. The same goes for the 26th status.

4.2. The second category

The No.3 state is transferred to the No.9 state or the No.21 state, the strategy is changed from “the one with the largest amount of reduction in reactive voltage correction” to “voltage correction” or “reactive correction”. And the voltage continues to decrease, the reactive power and voltage correction value will continue to decrease, and the adjustment amount will not change suddenly, so the No.3 state will not exist stably. The same is true for status 15th. State No.6, the power grid is in a state of excess reactive power. The strategy is "after voltage correction + reactive power correction component", the reactive power correction value and the voltage correction value will increase or decrease at the same time in the ratio of 1Mvar:0.04kV, and then return to the normal state. No.12 state, the grid is in a state of reactive power shortage, similar to No.6 state, the difference is that the reactive power correction value and voltage correction value will increase or decrease at the same time in the ratio of 1Mvar: 0.02kV, and turn to the normal state. No.19 state, grid reactive power surplus, using reactive power correction, the same strategy as No.21 state, that is, when the blocking signal is flashing, the strategy is not switched, and the commands of the No.19 and No.21 state pairs do not need to be switched. No.19 and No.25 state switching means that the reactive power value fluctuates near the upper limit. At this time, the No.25
state remains current, and the No. 19 state command is a reactive power correction command. During the switching period, the current voltage and the normal optimized voltage should be basically the same, the strategy connection is smooth. The same goes for the 23rd state. On the 20th state, the reactive power exceeds the upper limit and the demagnetization lockout means that the system voltage is abnormally low or even the voltage collapses, which is unreasonable. It is recommended to exit the system and give an alarm. The same is true for number 22. In the No. 7 state, the voltage is higher than the upper limit, the magnetization is blocked, and the voltage correction is adopted. The No. 7 and No. 9 conversion strategies are the same. The No. 7 and No. 25 conversion means that the actual voltage and the optimized voltage are both near the upper limit and the strategy connection is smooth. The same is true for No. 17 and No. 7 states. In the 8th state, the voltage is higher than the upper limit, and the demagnetization is blocked, which means that the area is over-reactive and the down-blocking is unreasonable. It is recommended to exit the system and give an alarm. The same is true for the 16th state.

4.3. The third category
No.2, 4, 5, 10, 11, 13, and 16 states are all unreasonable, and the reason is the same as that of No.8, and all adopt the strategy of exiting the alarm. 1 state cannot be maintained, voltage and reactive power will decrease rapidly under control, and return to one of No.3, 7, and 19 states, No.1-3 state transition, strategy does not switch; No.1-7 state transition means that the amount of reactive power has been reduced It is close to 0, so the amount of voltage reduction must be large, and the strategy is not switched. The same applies to No.1-19, so the strategy is smooth. No.14 status is the same.

After analysis, the suggested strategies are reasonable, which can avoid the problem of repeated state switching caused by the implementation of different strategies, resulting in system voltage oscillations.

5. Conclusion
An AVC voltage control strategy adjustment method belongs to the technical field of automatic voltage control. The article is to solve the problem that the existing AVC normal and abnormal state processing strategies will make the AVC unable to smoothly transition and repeatedly oscillate. The AVC voltage control strategy adjustment method described in this article analyzes the abnormal signals of the current state of the power grid and handles different situations differently. This method can realize the smooth transition of the control strategy, and realize the voltage optimization control in real time.

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