Analysis of coupling factors between high proportion wind power and ultra-high voltage DC

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Abstract. Due to the imperfect construction of supporting thermal power units, when wind power sources are in full swing, if DC low-power operation will inevitably lead to wind power abandonment, if DC high power operation is subject to fault transient overvoltage operation constraints, it will also cause power curtailment of wind power sources. In order to promote wind power consumption and lean management of DC influencing factors, this paper analyzes the number of supporting thermal units started, supporting unit power changed, wind power and connected substation power to find out the key factors of DC operating limit and wind power consumption. The validity of this paper was verified by a DC power grid simulation in a certain area.

1. Introduction
Wind power in the northwest region presents a large-scale access feature. To promote wind power consumption and resolve the serious mismatch between load and power supply, it is sent to the load intensive region through UHV DC[1-3]. The superposition of large-capacity, long-distance DC transmission and the uncertainty of wind power operation has led to a further increase in the difficulty of wind and fire bundling operation control of the AC-DC hybrid system[4-5].

In [6], the author obtained the steady-state characteristics of the AC/DC hybrid power grid by including different forms of power simulation AC/DC power grid models in PSCAD; in [7], the author proposed DC transmission schemes with different wind power output levels; in [8], the author analyzed the high wind farm voltage caused by DC faults, it may cause wind farm trawl problems, and suppress wind farm trawl from measures such as controlling DC power, optimizing wind power access methods, and improving equipment withstand voltage; in [9], the author adopted for the mechanism analysis of transient overvoltage during power disturbance of large-capacity DC, a fast calculation method for transient overvoltage of converter bus and fan is proposed; in [10], the author studied the AC/DC delivery under the condition of “wind and solar bundling” in Xinjiang Under the transient stability problem, and through additional control strategies to improve the transient stability of the system.
This paper studies the coupling relationship between UHV DC and AC systems and near-region wind power output, establishing simulation model in PSASP, analyzing in depth the main mechanisms that cause strong coupling between DC and wind power, and AC systems, and finds out the constraints on DC operation the key factors of power and wind power output can more effectively guide the safe and stable operation of the power grid and ensure the consumption of DC outgoing power and wind power.

2. Analysis of the impact of faults on the system

2.1. Analysis of the impact of AC faults on the system
During the failure of the AC line near the sending end converter station, the active and reactive power of the DC transmission instantaneously drops, and a large amount of surplus reactive power of the converter station is returned to the AC system, causing the bus voltage of the sending end substation to rise; failure of the AC line will cause Low-voltage ride-through of wind power gathering stations and wind turbines in the DC area, some of the units that do not have the low-voltage ride-through function may be directly disconnected from the grid. Low-voltage ride-through of the wind turbine or off-grid will cause the main power flow to be reduced, and the voltage along the line will generally rise, and the active power of the fan will be reduced. The reactive power surplus of the post-wind farm will further lead to high transient overvoltage.

From the above analysis, it can be seen that when the near area AC line fails, the transient overvoltage is mainly related to the DC power and the wind power in the near area; changing the DC and wind power output in PSASP to obtain the transient overvoltage curve is shown in figure 1.

![Figure 1. AC fault transient overvoltage curves under different DC and wind power](image)

It can be seen from figure 1 that the greater the DC power, the higher the transient overvoltage generated when the near-field AC line fault occurs; the greater the wind power output, the greater the number of low-voltage crossing wind turbines when the near-field AC line fault occurs, and the power flow is reduced and the power is reduced. The more severe the deficit, the higher the transient overvoltage.

2.2. Analysis of the impact of DC faults on the system
During the failure of the AC line near the receiving end converter station, it may cause the commutation failure of the sending end DC. If the continuous DC commutation fails but the blocking is not triggered, the safety control system will not cut off the AC filter and transmission of the converter station. The voltage at the sending end decreases first and then rises during the failure of DC commutation finally. The voltage drops at the receiving end causes the voltage at the sending end to decrease; the filter of the converter station and the near-region fan that have not been cut off cross or cause off-grid. Wind farm reactive power surplus causes high overvoltage at the sending end.

From the above analysis, it can be seen that the transient overvoltage of the wind turbine is mainly caused by the reactive power surplus of the DC and the wind farm. Thus, the number of supporting
thermal power units during the DC operation, the DC power, the active power of the connected transformer and other factors will all affect the Transient overvoltage related.

Figure 2 are the reactive power of the supporting unit and DC reactive power, the grid power change of the substation and wind turbine voltage when DC fault occurs.

Figure 2. transient supporting thermal and DC reactive power, wind turbine voltage and substation power curve during DC fault

It can be seen from figure 2 that the disconnection of the fan caused by the DC fault is related to the DC power and the output of the fan, mainly because the DC power determines the capacity of the filter input; the more the fan is turned on, the more reactive power compensation devices are configured. However, the supporting thermal power unit can suppress the transient overvoltage at the time of failure. Therefore, the simulation mainly simulates the relevant factors such as DC power, start-up mode, total wind power output and other related factors.

3. Simulation
The grid structure of the AC-DC hybrid power grid is shown as figure 3, plants 1-3 are DC supporting thermal power units, the substations AD are wind power collection areas, the AC line voltage level is 750 kV, the DC system is ±800 kV, the AC and DC systems Perform power exchange by contacting the substation.

Figure 3. Grid structure of simulation

3.1. Relationship between supporting thermal unit number and the fault transient overvoltage
To verify the impact of the number of supporting thermal power units on the transient overvoltage change of the fault, keeping the DC power, the power of the connected substation and the total output of the wind power are unchanged, reducing the number of starting units gradually, and increasing the number of supporting thermal power units when the DC continuous commutation fails The impact on the fault transient overvoltage is shown in table 1.
### Table 1. The influence of thermal unit on fault transient overvoltage

| Thermal number | Each thermal output/MW | DC power/MW | Connected substation power/MW | Wind power/MW | Transient overvoltage /p.u |
|----------------|------------------------|------------|-------------------------------|---------------|--------------------------|
| 8              | 313                    | 6500       | 4000                          | 6000          | 1.223                    |
| 7              | 357                    | 6500       | 4000                          | 6000          | 1.232                    |
| 6              | 417                    | 6500       | 4000                          | 6000          | 1.242                    |
| 5              | 500                    | 6500       | 4000                          | 6000          | 1.258                    |

It can be seen from table 1 that under the failure of continuous DC commutation, the transient voltage of the fault gradually rises as the number of supporting thermal power units is reduced. Therefore, the construction of DC thermal power units needs to be strengthened to reduce the transient transient overvoltage and improve the stability of the power grid.

3.2. The relationship between connected substation and fault transient overvoltage

To verify the impact of the reduction of the grid power on the transient overvoltage, keeping the number of supporting units, DC power, and the total output of the fans are unchanged, and reducing the grid power of the joint substation and increasing the output of the thermal power gradually. When the continuous DC commutation fails and fails the relationship between the lowering of the grid and the transient overvoltage of the fault is shown in table 2.

### Table 2. The influence of connected substation on fault transient overvoltage

| Thermal number | Each thermal output/MW | DC power/MW | Connected substation power/MW | Wind power/MW | Transient overvoltage /p.u |
|----------------|------------------------|------------|-------------------------------|---------------|--------------------------|
| 8              | 313                    | 6500       | 4000                          | 6000          | 1.223                    |
| 8              | 375                    | 6500       | 3500                          | 6000          | 1.216                    |
| 8              | 438                    | 6500       | 3000                          | 6000          | 1.214                    |
| 8              | 500                    | 6500       | 2500                          | 6000          | 1.213                    |

It can be seen from table 2 that under the failure of continuous DC commutation, the transient overvoltage of the fault decreases gradually as the power of the grid is reduced (and correspondingly increases the power of the supporting thermal power unit), and the thermal power supporting the grid is more stable than the grid.

3.3. Relationship between DC power and fault transient overvoltage

To verify the impact of DC power reduction on transient overvoltage, ensure that the number of supporting units turned on, the power of the combined substation off grid, and the total output of the fans remain unchanged, and gradually reduce the DC power and correspondingly reduce the power of the supporting thermal power unit. When the continuous DC commutation fails, the DC The effect of power reduction on fault transient overvoltage is shown in table 3.

### Table 3. The influence of DC power on fault transient overvoltage

| Thermal number | Each thermal output/MW | DC power/MW | Connected substation power/MW | Wind power/MW | Transient overvoltage /p.u |
|----------------|------------------------|------------|-------------------------------|---------------|--------------------------|
| 8              | 438                    | 6500       | 3000                          | 6000          | 1.214                    |
| 8              | 375                    | 6000       | 3000                          | 6000          | 1.198                    |
| 8              | 313                    | 5500       | 3000                          | 6000          | 1.187                    |
| 8              | 250                    | 5000       | 3000                          | 6000          | 1.176                    |
It can be seen from table 3 that as the DC power decreases, the fault transient gradually decreases, and reducing the DC power can improve the stability of the power grid, but it will reduce the output power (including wind power), which is not conducive to the absorption of wind power. Reasonable choice between degree and economy.

### 3.4. Relationship between wind power and fault transient overvoltage

To verify the impact of the reduction of wind power output on transient overvoltage, ensure that the number of supporting units and the DC power remain unchanged, reduce the output of wind power and correspondingly increase the output of supporting thermal power, and reduce the output of wind power when the continuous DC commutation fails. The effect of overvoltage is shown in table 4.

| Thermal number | Each thermal output/MW | DC power/MW | Connected substation power/MW | Wind power/MW | Transient overvoltage /p.u |
|----------------|------------------------|-------------|-------------------------------|---------------|---------------------------|
| 8              | 313                    | 6500        | 4000                          | 6000          | 1.223                     |
| 8              | 375                    | 6500        | 3500                          | 5500          | 1.211                     |
| 8              | 438                    | 6500        | 3000                          | 5000          | 1.203                     |
| 8              | 500                    | 6500        | 2500                          | 4500          | 1.200                     |

It can be seen from table 4, as the wind power output decreases, the fault transient overvoltage gradually decreases, and reducing the power of the wind power can improve the stability of the power grid, but it is not conducive to the absorption of wind power. Therefore, the relationship between the size of the wind power output and the safety of the power grid needs to be considered.

### 3.5. Relationship between wind power, DC power and fault transient overvoltage

To verify the impact of the wind power output, DC power and the fault transient overvoltage, ensure that the number of supporting units turned on and the DC link substation remain unchanged, gradually reduce the output of wind power and increase the DC power, DC continuous commutation failure fault. The impact of wind power output decrease and DC power increase on fault transient overvoltage is shown in table 5.

| Thermal number | Each thermal output/MW | DC power/MW | Connected substation power/MW | Wind power/MW | Transient overvoltage /p.u |
|----------------|------------------------|-------------|-------------------------------|---------------|---------------------------|
| 8              | 313                    | 6000        | 3500                          | 6500          | 1.211                     |
| 8              | 375                    | 6500        | 3500                          | 6000          | 1.216                     |
| 8              | 438                    | 7000        | 3500                          | 5500          | 1.221                     |
| 8              | 500                    | 7500        | 3500                          | 5000          | 1.226                     |

It can be seen from table 5 that as the output of wind power decreases and the DC power increases, the fault transient overvoltage gradually increases, and the reduction of the output of wind power has a smaller impact than the corresponding increase in DC power. The influence is greater, and the influence of DC power on fault transient overvoltage needs to be considered more.

### 4. Conclusion

From the above simulation, we can conclude that:

The fault transient overvoltage is related to the number of supporting start-up units, the output of the supporting thermal power units, DC power, the power of the connected substation off-grid, and the...
output of wind power. The number of supporting start-up units, the supporting thermal power output and the fault transient overvoltage have a positive correlation. Substation, wind power output and DC power have a negative correlation with fault transient overvoltage. The relationship between DC power and wind power output has a "this trade-off", but DC power has a greater impact, and comprehensive evaluation and trade-offs are needed in terms of DC and wind power consumption.

It can be seen from the above analysis that the main causes of transient overvoltage of the fan are factors such as DC filter capacity and fan reactive power compensation. In order to suppress the transient overvoltage, on the one hand, it is necessary to fundamentally solve the constraints of the fan's ability to withstand overvoltage. On the other hand, it is necessary to take the role of absorbing reactive power during the transient process and reducing the system reactive power surplus. Add centralized or decentralized dynamic reactive power compensation device or camera to evaluate transient overvoltage suppression effect.

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