Adaptive Droop Control for DC Voltage Deviation and Power Sharing in Multi-terminal DC(MTDC) Grids

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Abstract: Voltage source converter multi-terminal DC system(VSC-MTDC) have been used in many applications due to their many advantages. With conventional droop control, the voltage and power of the stable point are on a straight line with a specific slope. When subjected to a power disturbance, the voltage quality may be deteriorated or the power distribution effect of the converter station may be deteriorated. In this paper, a new adaptive control strategy is proposed for VSC-MTDC. The control system focuses on voltage quality at low loads and power distribution at high loads. It not only ensures voltage quality but also meets power distribution requirements. Simulation results are provided to verify the validity and effectiveness of the proposed method.

Keywords: multi-terminal DC, adaptive droop control, power sharing, DC voltage deviation

1. Introduction

In recent years, research on new energy access to the power grid has received extensive attention. HVDC transmission system is the main way for new energy grid connection, and VSC-HVDC has become a hot spot with its many advantages[1]. The traditional two-terminal DC transmission system is used to realize interconnection between multiple power grids, which requires multiple DC transmission lines, and the cost and operation cost are high. Compared to traditional two-terminal DC transmission, MTDC operates more flexibly and with higher reliability[2]. Therefore, the control problem of multi-terminal HVDC transmission system has become the key to the development of power systems[3,4].

Voltage droop control adjusts the power by adjusting the DC voltage. When the power fluctuates, the control mode adjusts each of the converter stations to share the power difference. This method is highly reliable and has no voltage oscillations. The disadvantage of this type of control is that it is difficult to achieve a trade-off between power distribution and voltage fluctuations[5].

An adaptive droop control is proposed in [6], but the form of the method is too complicated. The scheme with the highest transmission efficiency in power distribution is proposed in [7], but it is complicated and does not consider the problem of voltage quality. In the [8], in order to balance the accuracy of voltage quality and power distribution, a stable reference point scheme for real-time updating is proposed, but the problem of this scheme is that the response speed is slow and the system is unstable. In the [9], although the voltage quality is ensured, the droop coefficient calculation time is too long and the calculation is complicated. A new control scheme is proposed in [10], but the jitter problem caused by slip film control cannot be avoided.
The problem in all of the above documents is that although it is proposed to pay attention to voltage regulation when the power of the converter station is small and to pay attention to power regulation when the power is large, it is not accurate enough. To solve this problem, the adaptive control method proposed in this paper not only retains the characteristics of the adaptive droop control mentioned above, but also can clearly define the droop control ability according to the actual operating conditions. Simulation results are provided to verify the validity and effectiveness of the proposed method.

2. VSC modeling and control modes

2.1. Modeling of a VSC-HVDC Station
The inner current loop controls the voltage of the upper and lower arms of each phase of the converter by accepting the current command by the outer loop power control to achieve voltage and power control of the converter station.

The outer loop power control requires a reference current value for the inner loop current control through a specific operating mode. Outer loop power control includes active power and reactive power controllers. The active power controller is responsible for regulating the active power or the DC voltage, and the reactive power controller is responsible for mediating the reactive power or the AC voltage amplitude. Power equation in $dq$ axis can be expressed as

$$
P = u_d i_d + u_q i_q$$

$$
Q = u_d i_d - u_q i_q$$

(1)

In particular, when the $d$ axis coincides with the grid voltage space vector, the following relationship can be express:

$$
P = u_d i_d$$

$$
Q = -u_q i_q$$

(2)

2.2. DC voltage and power control models
There are three control modes of VSC-MTDC: constant voltage control mode, constant power control mode and voltage droop control mode. The constant voltage control mode maintains the voltage of the converter station unchanged, and the power can be varied within the rated range. Similarly, the constant power control is to ensure that the power does not change within the rated range. Voltage droop control is to distribute power according to a certain voltage drop. Figure 1, Figure 2 and Figure 3 show the constant power, constant power and droop control, respectively.

3. Adaptive droop control for MTDC

3.1. Fixed droop control
The drooping characteristic of the conventional droop control is a straight line with a fixed slope, which can be expressed as

\[ a \times (U - U_{ref}) + b \times (P - P_{ref}) = 0 \]  \hspace{1cm} (3)

Where \( U \) and \( P \) are the DC bus voltage and output active power of the converter respectively. \( U_{ref} \) and \( P_{ref} \) refer to the reference values. Voltage and power reference points can be selected as \( U_{ref} = U_{max} \) and \( P_{ref} = 0 \) respectively (Where \( U_{max} \) represents the highest operating voltage of the converter station). The relationship between voltage and power can be obtained as follows

\[ U = U_{max} - RP \]  \hspace{1cm} (4)

Here the definition of the droop coefficient is

\[ R = \frac{b}{a}, \ a \neq 0 \]  \hspace{1cm} (5)

Therefore, this equation becomes

\[ \Delta U = -R\Delta P \]  \hspace{1cm} (6)

### 3.2. Adaptive droop control

As mentioned above, voltage deviation and power distribution are contradictory. The droop coefficient of the conventional droop control is a fixed constant, which in many cases does not meet the requirements of voltage deviation and power distribution. If the voltage deviation is too large, the voltage quality of the MTDC system will drop. If the power distribution is not performing well, it may cause some of the converter stations to exceed the power limit. In response to this problem, this paper proposes flexible droop control. This paper proposes voltage adaptive droop control as follows:

\[ U = U_{ref} - \alpha P^{\beta} \]  \hspace{1cm} (7)

From (8) we can get the adaptive droop coefficient:

\[ R' = \frac{\partial U}{\partial P} = -\alpha \beta P^{\beta-1} \]  \hspace{1cm} (8)

Where \( \alpha \) and \( \beta \) are pending coefficients.

Determine \( \alpha \) and \( \beta \) according to the following two boundary conditions:

1. According to the maximum capacity of the converter station and the maximum voltage (5%\( U_{max} \)) allowed to fall, the droop coefficient at the full load of the converter station can be determined:

\[ R'(P_{max}) = \frac{\Delta U_{max}}{P_{max}} \]  \hspace{1cm} (9)

2. It is desirable to have better voltage quality when there is less power fluctuation. Therefore, it is designed to have a large power distribution capability under small load conditions. It is advisable to set the total power of the converter station to be adjusted by half of the maximum allowable drop voltage:

\[ R'(0.8P_{max}) = \frac{0.5\Delta U_{max}}{0.8P_{max}} \]  \hspace{1cm} (10)

### 4. Simulation

In order to verify the effectiveness of the proposed control method, a four-terminal VSC-MTDC system is built in PSCAD/EMTDC. Here VSC1 and VSC2 use droop control, and VSC3 and VSC4 use constant voltage control. The simulation parameter table of the system is shown in Table 1.
Table 1 Parameter of MTDC system

| parameter                                         | value |
|---------------------------------------------------|-------|
| Rated DC voltage $U_{ref}/$kV                     | 1000  |
| Capacity of VSC1 (voltage droop) / WM             | 1200  |
| Capacity of VSC2 (voltage droop) / WM             | 800   |
| Capacity of VSC3 (constant power) / WM            | 1000  |
| Capacity of VSC4 (constant power) / WM            | 1000  |
| Line resistance (1-5)/ohm                         | 2.5   |
| Line resistance (2-5)/ohm                         | 0.75  |
| Line resistance (3-6)/ohm                         | 0.5   |
| Line resistance (4-6)/ohm                         | 2     |
| Line resistance (5-6)/ohm                         | 3     |

(1) Light load conditions: For example, power of VSC3 is -200 MW, power of VSC4 rises from -200 MW to -400 MW at 4 s.

Figure 4 shows that the adaptive droop control voltage is better than the fixed droop control voltage quality under light load conditions. Figures 5 and Figure 6 show that the two control modes are satisfactory in terms of power allocation.

(2) Heavy load conditions: For example, power of VSC3 is -900 MW, and power of VSC4 is raised from -200 MW to -900 MW at 4 s. In the case of heavy load, the power distribution capability is more important in consideration of the problem of overloading of the converter station.

It can be seen from Figure 7 and Figure 8 that in the case of heavy load, VSC2 exceeds the rated power of 800 MW when the fixed droop control is used, but VSC2 operates within the rated power range in the adaptive droop control.
As shown in Figure 9, the voltages of the two control modes under heavy load. The voltage quality with adaptive droop control is significantly better than that of the fixed droop control.

5. Conclusion
Aiming at the contradiction between voltage quality and power allocation when the power of the converter station fluctuates, this paper proposes an adaptive voltage droop control strategy. Depending on the size of the load, the focus of the droop control is also different. Not only does it improve the voltage quality, but it also increases the power distribution capability of the converter station. Effectiveness of flexible droop control verified by PSCAD/EMTDC simulation.

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