The calculation method of optimized AC choppers capacity in islanded MMC-HVDC system

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Abstract. In order to ensure the safety of renewable energy generation integration system through islanded MMC-HVDC, the AC choppers with the same capacity as sending end converter station are equipped in current projects. However, considering the actual operation needs, it is not necessary to equip so many AC choppers. The optimal capacity of the AC choppers can be calculated according to the most serious fault. The calculated capacity can meet two requirements. One is the renewable energy generation units just start to cut off when the DC voltage reaches the overvoltage limit value. Another one is to minimize the cost and floor area of the AC choppers. It can ensure that the converter station devices is not be damaged in the condition of lowest economic cost. A three-terminal and a four-terminal renewable energy generation integration system through islanded MMC-HVDC are built in PSCAD, which verifies the correctness of the theoretical analysis.

1. Introduction

MMC-HVDC can provide voltage support, dynamic compensation and reactive power for renewable energy generation system[1,2,3,4]. Wind and solar energy are mainly distributed in the Northwest China, which have the characteristics of vastness, isolation and passivity. In order to solve the problem of large-scale renewable energy power generation consumption, Zhangbei MMC-HVDC project is constructing by State Grid Corporation of China. When the renewable energy generation is sent out through islanded MMC-HVDC system, it can realize multi-power supplies and multi-infeed systems, which has great advantages over conventional HVDC.

However, the large number of power electronic devices in MMC-HVDC lead to the low inertia and weak damping performance of the whole system. Further, the response time scales of converter station and new energy generation units are quite different. If the system is disturbed or the converter station is blocked, the unbalanced power caused by the disturbance or fault will charge the capacitors and finally causes over-voltage or over-current in tens of milliseconds, while the response time of renewable energy generation units is in hundreds of milliseconds and the transmission power of integration system is high. It means that the unbalanced power caused by the fault is uncontrollable and the fault will be further extended, which will inevitably damage the converter station and cause the whole system shutdown. Compared with MMC-HVDC direct connected AC grid system, the renewable energy generation integration system through islanded MMC-HVDC has weaker ability to resist faults and disturbances, and the safe and stable area of converter station is smaller. Therefore, it is necessary to reduce unbalanced power quickly to avoid irreversible damage to converter station. For
this purpose, the commonly used method in engineering is to adapt energy dissipation resistance which called chopper, which can consume the surplus power of the MMC-HVDC system as heat[5].

According to the different installation location and principle, chopper can be divided into AC chopper and DC chopper. DC chopper has disadvantages in economic cost, reliability, and volume, which limits its wide application[6,7]. The AC chopper technology is simple to realize and thyristor is cheap, so this paper focuses on AC chopper.

Literature [8] proposes an adaptive dissipation control strategy associated with the AC choppers, but the ratio of the AC choppers to surplus power is not analyzed. Literature [9] proposes to consume surplus power through AC chopper at the AC side of the converter station in Zhangbei MMC-HVDC project, but the capacity of AC chopper is the same as that of the sending converter station and new energy generation system. Considering the cost and floor area of AC chopper, it is non-essential to adopt AC chopper with the same capacity as new energy generation system. Therefore, it is necessary to study the optimal AC choppers capacity in renewable energy generation integration system through islanded MMC-HVDC.

In this paper, the principle of the AC chopper and the calculation method of optimal capacity are analyzed. The results show that the optimal capacity of the AC chopper is related to the switching-in time of the AC chopper, the equivalent capacitance of converter station, overvoltage limit value, response time of new energy units, and the ability of balance station to transform power. Finally, the correctness of the analysis is verified by simulation.

2. The principle and calculation method of the AC chopper optimal capacity

The schematic diagram of renewable energy generation integration system through islanded MMC-HVDC is shown in the Figure 1. AC chopper is configured at AC side of sending terminal converter station.

![Figure 1. Renewable energy generation integration system through islanded MMC-HVDC four-terminal MMC-HVDC](image)

2.1. The principle of the AC chopper

The AC chopper includes a transformer, thyristors and energy dissipation resistors, etc. Due to the low withstand voltage of the thyristor, a step-down transformer should be added between the AC chopper and the AC bus. The switching-in of energy dissipation resistance is controlled by the opening of anti-parallel single-phase thyristors. In one cycle, each thyristor can only conduct positive half cycle or negative half cycle alternately, which can be used in large current situations. However, the thyristor is a semi-controlled device, the switching-off of the energy dissipation resistor is not controllable. The condition that the thyristor is turned off must be met, that is to say, AC choppers can be withdrawn from operation only when the current is at the natural zero crossing point. This means that the switching-off of AC chopper will have a time delay, which will bring a certain disturbance to the system. Therefore, in the actual project, the method of reducing the fluctuation is to switching AC chopper by group.
2.2. The calculation method of the AC chopper optimal capacity

In Zhangbei project, the capacity of equipped AC chopper is equal to the full power operation of the sending terminal converter station[9]. However, considering the cost and floor area, it is necessary to study the optimal equipped capacity of the AC choppers.

The most serious fault is that the receiving end converter station is blocked. At this time, the surplus power in the dc network is the most so the capacity of AC choppers that needs to be put into is the most. Therefore, this paper takes the block fault of the receiving converter station as the research object, and analyzes the optimal equipped capacity of AC chopper that should be switching-in.

Without considering the equipment of AC chopper, the balance station with constant DC voltage control strategy will transfer some surplus power after the receiving end converter station is blocked, which depends on the power capacity of the balance station. The remaining surplus power can only charge the converter station capacitors. Its principle can be expressed as formula (1).

\[ W_t = \frac{1}{2} \sum_{j=1}^{m} C_j (U_{i_j}^2 - U_0^2) = \Delta P_C^2 t \]  

\[ \Delta P_C^2 = P_{block} - (P_{max} - P_b) \]  

In the formula (1), \( C_j \) is the equivalent capacitance of the j-th converter station. The equivalent capacitance coefficient is calculated by the method of reference [10]. \( U_i \) is the is the maximum withstand voltage of DC power grid. \( U_0 \) is the initial value of DC grid voltage. \( \Delta P_C^2 \) is the total surplus power in the DC grid. \( P_{block} \) is active power during normal operation of the blocked receiving end converter station, \( P_{max} \) is the maximum active power of balance converter station, \( P_b \) is the active power during normal operation of the balance converter station. The analysis of this paper is based on the foundation that the balance station can transform the surplus power rapidly.

The ultimate reason of equipping AC chopper is to solve the problem that the overvoltage time of DC power grid does not match the cut-off time of renewable energy generation units. So as long as the equipped AC choppers can ensure that the voltage of converter station does not exceed limit value before the cut-off of renewable energy generation units, the safety of converter station devices can be guaranteed.

It is assumed that the ratio of the AC chopper capacity to the surplus power in the dc grid is \( x:1 \). \( t \) is the time when the DC voltage reaches the over-voltage limit value. \( t_i \) is the time when the renewable energy generation units cut off. AC chopper can be put into operation quickly in a few milliseconds so the switching-in time of the AC chopper is \( t_2(t_2 < t_1) \). The relationship between surplus energy and power in DC power grid is

\[ W_z = \Delta P_C^2 t_2 + \Delta P_C^2 (1 - x)(t_i - t_2) = \Delta P_C^2 t_1 - x\Delta P_C^2 (t_i - t_2) \]  

The new energy generation units have to be cut off before the DC voltage reaches the overvoltage limit value. In order to meet the requirement, \( t_i \equiv t_1 \) must be satisfied. Therefore, the relationship between the DC network surplus energy when the AC choppers are adopted and not adopted can be expressed as

\[ W_z \leq W_t = \frac{1}{2} \sum_{j=1}^{m} C_j (U_{i_j}^2 - U_0^2) \]  

Substituting formula (3) into formula (4)

\[ x \geq \frac{t_i}{t_i - t_2} - \frac{1}{2\Delta P_C^2 (t_i - t_2)} \sum_{j=1}^{m} C_j (U_{i_j}^2 - U_0^2) \]  

From formula (5), it can be seen that the more quickly the time to switch in the AC choppers, the smaller the x and the lower the cost. Meantime, the requirement of response time of thyristor control becomes higher. Therefore, both the cost and the control response time should be taken into account when \( x \) is determined. The optimal AC choppers capacity that should be equipped is

\[ P_{chopper} = x_{\text{max}} \Delta P_C^2 = \left[ \frac{t_i}{t_i - t_2} - \frac{1}{2\Delta P_C^2 (t_i - t_2)} \sum_{j=1}^{m} C_j (U_{i_j}^2 - U_0^2) \right] [P_{block} - (P_{max} - P_b)] \]
From formula (6), it can be seen that $P_{\text{chopper}}$ is related to the switching-in time of the AC choppers, the equivalent capacitance of converter station, overvoltage limit value, response time of renewable energy generation units, and the ability of balance station to transform power.

3. Simulation verification

In this paper, renewable energy generation integration system through three-terminal and four-terminal islanded MMC-HVDC are built.

The structure and positive direction of power flow in the three-terminal system is similar to that shown in the Figure1., except that there is no MMC4. MMC1 and MMC3 are directly connected through the line. Connected to new energy power generation system, MMC1 is the sending end converter station with the islanded V/F control strategy. MMC2 is the balance converter station with the constant DC voltage control strategy. MMC3 is the receiving end converter station with the constant active power control strategy. The parameters of the three-terminal system are shown in Table 1.

| The number of converter station | Rated capacity(MVA) | Rated active power(MW) | Capacitance value of sub-module(mF) | The number of each phase sub-modules (N) | Rated DC voltage(kV) |
|---------------------------------|---------------------|------------------------|-----------------------------------|------------------------------------------|----------------------|
| MMC1                            | 1700                | 1500                   | 7                                 | 100                                      | 500                  |
| MMC2                            | 850                 | 750                    | 3.8                               | 100                                      | 500                  |
| MMC3                            | 1700                | 1500                   | 7                                 | 100                                      | 500                  |

According to the law of conservation of energy

$$P_1 = P_2 + P_3$$

(7)

When MMC3 is blocked at 2s,

$$\Delta P_\Sigma = P_3 - (P_{2\text{max}} - P_2) = P_1 - P_{2\text{max}}$$

(8)

So formula (6) can be expressed as

$$P_{\text{chopper}} = x_{\text{min}} \Delta P_\Sigma = \sum_{j=1}^{2} \left( \frac{1}{t_j - t_{j-1}} - \frac{1}{2(P_j - P_1)} \right) \sum_{j=1}^{m} C_j (U_j^2 - U_0^2) (P_j - P_{1\text{max}})$$

(9)

Using the parameters of a practical project, $t_1=160$ms, $t_2=4$ms and $U_1=1.3U_0$. The optimal ratio $x_{\text{min}}$ between the capacity of AC chopper and the surplus power can be calculated as 0.37. So $P_{\text{chopper}}=240.5$MW. It saves 1259.5MW of the AC choppers capacity. The simulation verification waveform is shown in the Figure2. and Figure3.

As can be seen from Figure2., The 240.5MW AC chopper is put into operation quickly after the fault occurs in 2s. 240.5MW active power of $P_1$ at the sending end converter station is consumed so the rising time of $U_{\text{dc, chopper}}$ slows down. $U_{\text{dc}}$ is the DC voltage without AC chopper adopted. $U_{\text{dc, chopper}}$
rises to 650kV after 160ms in case of blocking fault. The capacity of the AC chopper that calculated by formula (9) just meets the action time of new energy units when the DC grid voltage reaches the limit value.

The structure of the four-terminal system is shown in the Figure1. MMC1-MMC3 is same as the above three-terminal system. MMC4 and MMC1 are controlled in the same way. The parameters of MMC4 are shown in Table2.

Table2. The parameters of MMC4.

| The number of converter station | Rated capacity(MVA) | Rated active power(MW) | Capacitance value of submodule(mF) | The number of each phase sub-modules (N) | Rated DC voltage(kV) |
|---------------------------------|--------------------|------------------------|-----------------------------------|-----------------------------------------|---------------------|
| MMC4                            | 850                | 750                    | 3.8                               | 100                                     | 500                 |

Similarly, the situation that MMC3 is blocked in 2s is analyzed as followed.

\[ P_1 + P_4 = P_2 + P_3 \]  
\[ \Delta P_2 = P_3 - (P_{2\text{max}} - P_2) = P_1 + P_4 - P_{2\text{max}} \]

According to formula (6),  \( P_{\text{chopper}} = 1125 \text{MW} \). It saves 1125MW of the AC choppers capacity. The four terminal system needs a large capacity of the AC choppers. In order to reduce the DC voltage fluctuation, the AC choppers are switched in by 3 groups. Each group is 375MW. The simulation verification waveform is shown in the Figure4. and Figure5.

![Figure4](image1.png)  
**Figure4.** The operation power of MMC1

![Figure5](image2.png)  
**Figure5.** The overvoltage time of DC grid

After the blocking fault occurs, the three groups of AC choppers are put into operation. \( U_{\text{dc chopper}} \) rises to 650kV in 170ms, slightly slower than 160ms, which is due to the large fluctuation of DC voltage. So the simulation result is in small error with the theoretical calculation result.

### 4. Conclusion

The calculated capacity of AC chopper can ensure the safety of converter station and minimize the cost and floor area.

The optimal capacity of the AC chopper is related to the input time of the AC chopper, the equivalent capacitance of converter station, overvoltage limit, response time of renewable energy generation units, and the ability of balance station to transform power. Also, for different systems, the fault severity is different. So, the required AC chopper capacity is different. The larger the capacity, the more likely to cause DC voltage fluctuations. It will make the theoretical calculation results deviate from the actual value.

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