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# Study on stability evaluation in multi-send hybrid AC/DC transmission system

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**Abstract.** Our country has shown the significant features of high voltage direct current (HVDC) including multi-infeed and multi-send. Compared to multi-infeed system, there are a lot of weakness in the multi-send system, such as the grid structure is single and weak, which makes the interaction between AC and DC to a greater extent affect the stability of the multi-send hybrid AC/DC transmission system. In order to evaluating the system strength in multi-send hybrid AC/DC transmission system, for the first time, this paper proposed the general formula and simplified formula for multi-send short-circuit ratio (MSSCR), which accounts for the coupling between multi-dc projects. Considering the control characteristics of rectifier in sending-side and combining the maximum power curve method, the criticality of MSSCR is proposed. Multi-send critical short-circuit ratio (MSCSCR) is deduced by the quasi steady-state equation of rectifier, to determine the multi-send system is strength enough or not. The proposal of MSSCR is of considerable significance for effectively evaluating the stability performance of the multi-send AC/DC hybrid transmission system, completing the short-circuit ratio theoretical system, and consolidating the short-circuit ratio index status.

## 1. Introduction

At present, China's high voltage direct current (HVDC) transmission is mostly concentrated in East China and South China power grids is the most typical, with 7 HVDC in East China Power Grid: 4 HVDC project: Yihua, Genan, Linfeng, Longzheng, , and 3 UHVDC project: Fengfu, Xizhe, Sujin, 8 HVDC in Guangdong Power Grid: 6 high-voltage DC project: Tianguang, Sanguang, Xiluodu to Guangdong double-back, Guiguang double-back, and 2 UHVDC project: Yunguang, Nuozhadu. The drop points of HVDC transmission are concentrated in energy-intensive areas such as northwest and southwest. several power grids of China have shown the important characteristics of DC multi-infeed and multi-send, and their scale is rare in the world.

The sending end of the multi-send hybrid AC/DC transmission system most chose at an energy enrichment place, the DC falling points are dense, the DCs are closely coupled, and the power grid structure is simple and relatively weak. Compared with the receiving end system, interactions between DC and DC, DC and AC have a greater impact on the stability of the sending end system. When the sending end system of the hybrid AC/DC transmission system is relatively weak, the slight power disturbance will also cause the converter bus voltage to fluctuate drastically, causing the rectifier to trigger phase shift, which affects the DC system operation. In severe cases, it may cause inverter commutation failed. When the commutation failure occurs on the inverter side, causing DC blocking, a large power surplus occurs at the sending end, and a huge power shortage occurs at the receiving end.



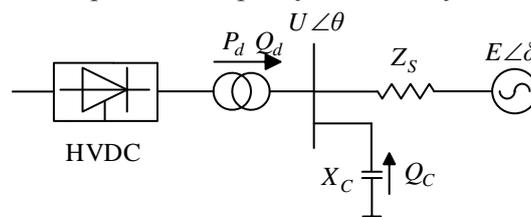
At this time, due to the closed DC channel, the reactive power compensation device such as the sending end system filter has a slower removing action, and excess reactive power is sent to the sending end system, resulting in overvoltage of the transmitting terminal commutation bus. And DC is equivalent to the load on the sending end system, and the load shedding caused by DC blocking will also cause temporary overvoltage and frequency problems. These stability problems threaten the safe and stable operation of multi-send hybrid AC/DC transmission system. Therefore, it is urgent to propose indicators to measure the strength of multi-send hybrid AC/DC transmission system, and it is of great significance to study the stability of multi-send hybrid AC/DC transmission system.

This paper starts from the static stability evaluation index of power system, short-circuit ratio (SCR) and multi-infeed short-circuit ratio (MISCR), and affirms its index significance. Applying the concept of SCR and MISCR in multi-send hybrid AC/DC transmission system, the multi-send short-circuit ratio (MSSCR) is proposed. The maximum power curve method is used to study the criticality of MSSCR, and the value of the multi-send critical short-circuit ratio (MSCSCR) is given. The MSSCR has enriched and improved the concept of the SCR index, and effectively evaluated the stability performance of the multi-send hybrid AC/DC transmission system.

## 2. SCR and MISCR

### 2.1. SCR

The mutual coupling between the AC system and the DC system depends to a large extent on the relative power of the HVDC transmission rated capacity of the AC system. For the equivalent single-infeed DC system shown in Fig.1, the International Council on Large Electric Systems (CIGRE) proposed short-circuit ratio (SCR) as a quantitative indicator of the strength of the AC system [1]. It refers to the ratio of the three-phase short-circuit capacity of the AC system  $S_{ac}$  to the rated DC power  $P_{dN}$  of the HVDC transmission connected to it, as shown in Equation 1. This indicator can better measure the voltage support capability of the AC system, and provides an evaluation index for the static stability of the AC system, which has been widely recognized. In Fig.1, the virtual frame part is the receiving end AC system;  $E$  is the AC system equivalent electromotive force;  $P_d$ ,  $Q_d$  are the DC active power and reactive power of the converter station;  $U$  is the commutating bus voltage;  $Q_c$  is the converter station reactive power compensation capacity;  $Z_s$  is the system equivalent impedance.



**Figure 1.** Diagram of single infeed system

$$SCR = \frac{S_{ac}}{P_{dN}} \quad (1)$$

Based on the short-circuit ratio indicator, taking into account the influence of the reactive power compensation of the converter station, the effective short-circuit ratio (ESCR) index can be obtained.

$$ESCR = \frac{S_{ac} - Q_c}{P_{dN}} \quad (2)$$

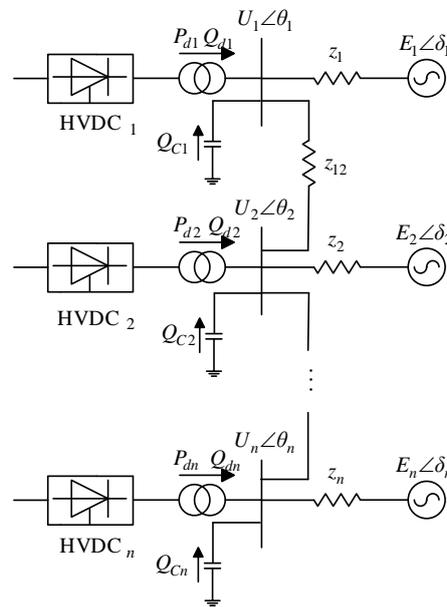
For the short-circuit ratio indicator, it is usually used for design planning, and the denominator often takes the DC rated active power  $P_{dN}$ . For operation, such as DC power reduction operation or system operation mode change, the actual operation  $P_d$  is less than the rated active power  $P_{dN}$ , so the short-circuit ratio indicator obtained always has

$$SCR = \frac{S_{ac}}{P_{dN}} \leq \frac{S_{ac}}{P_d} \quad (3)$$

That is, the SCR under rated operating conditions is more stringent. If the rated operation can meet the requirements of static and stable operation, the operating requirements can be met after the power reduction or operation mode is changed, and the stability margin is greater. This further determines the index meaning of the SCR, and the SCR indicators are discussed below in terms of rated operating conditions.

## 2.2. MISCR

With the development of high-voltage direct current transmission, there are many cases where the DC drop point is close and mutual influence. In the research report, CIGRE defined the multi-infeed interaction factor (MIIF) to account for the coupling between DCs<sup>[2]</sup>.



**Figure 2.** Diagram of hybrid AC/DC transmission system

The meaning is: multi-infeed as shown in Fig.2, in the simplified model of the hybrid AC/DC transmission system, the symmetrical three-phase reactor is input to the commutating bus bar  $i$ , so that the voltage drop on the bus bar is exactly 1%. At this time, the ratio of the voltage variation of the commutating bus bar of the DC subsystem  $j$   $\Delta U_j$  and the voltage changes of the  $i$ -th commutation bus

$\Delta U_i$ , is the MIIF, which is

$$MIIF_{j,i} = \frac{\Delta U_j}{\Delta U_i}$$

With the introduction of MIIF, the SCR indicator has also been developed. Following the SCR index in single-infeed DC system, the multi-infeed interaction factor MIIF and the multi-DC coupling relationship are evaluated, and the other DC coupling effects are evaluated according to the coupling degree and superimposed on the current DC power. The SCR forms a multi-infeed short-circuit ratio (MISCR) and a multi-infeed effective short-circuit ratio (MIESCR)<sup>[3]</sup>. Its definition is as follows

$$MISCR_i = \frac{S_{aci}}{\bar{P}_{diN}} = \frac{S_{aci}}{P_{diN} + \sum_{j=1, j \neq i}^n MIIF_{j,i} \cdot P_{djN}} \quad (4)$$

$$MIESCR_i = \frac{S_{aci} - Q_{ci}}{\tilde{P}_{diN}} = \frac{S_{aci} - Q_{ci}}{P_{diN} + \sum_{j=1, j \neq i}^n MIIF_{j,i} \cdot P_{djN}} \quad (5)$$

In fact, in the definition of SCR, MIIF and MISCR, it can be seen that although the target is the receiving end of hybrid AC/DC transmission system, the concept is equally applicable to the sending end, can carry out concept migration to evaluate the stability performance of multi-send hybrid AC/DC transmission system.

### 3. MSSCR

For multi-send hybrid AC/DC transmission system, similar multi-infeed interaction factor indicators can also be used to measure the mutual coupling between multiple-send DCs, which is defined as multi-send interaction factor (MSIF).

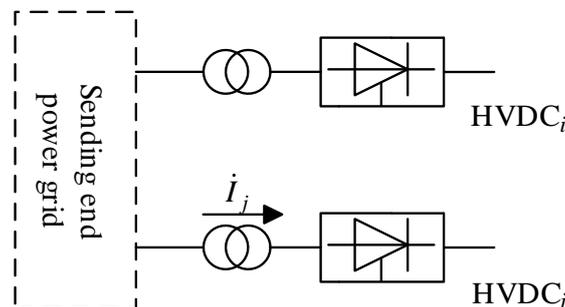
$$MSIF_{j,i} = \frac{\Delta U_j}{\Delta U_i} \quad (6)$$

Analogous to the SCR and MISCR, a multi-send short-circuit ratio (MSSCR) is proposed, which takes into account the interaction between multiple DCs. The expression is as shown in equation (7), where  $S_{aci}$  is the three-phase short-circuit capacity,  $\tilde{P}_{diN} = P_{diN} + \sum_{j=1, j \neq i}^n MSIF_{j,i} \cdot P_{djN}$  is the equivalent DC rated power, in which  $P_{diN}$  is the rated power of  $i$ -th DC, and  $P_{djN}$  is the rated power of other  $n-1$  DC.

$$MSSCR_i = \frac{S_{aci}}{\tilde{P}_{diN}} = \frac{S_{aci}}{P_{diN} + \sum_{j=1, j \neq i}^n MSIF_{j,i} \cdot P_{djN}} \quad (7)$$

In the multi-send hybrid AC/DC transmission system shown in Fig.3, the virtual frame part is the sending end power grid, and the DC is sent out for two of them. Considering the  $i$ -th and  $j$ -th DC, according to the node voltage equation  $\dot{U}_{ac} = Z_{BUS} \cdot \dot{I}_{ac}$ , the current  $\dot{I}_j$  is injected at the node  $j$ , and the voltage change caused by this current at the node  $i$  is as equation (8).

$$\Delta \dot{U}_{ij} = Z_{ij} \cdot \dot{I}_j \quad (8)$$

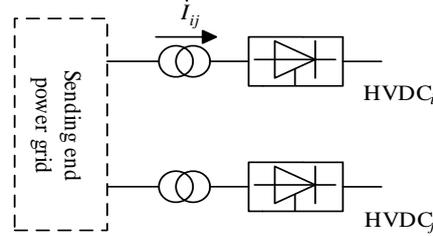


**Figure 3.** Diagram of hybrid AC/DC transmission system included two DC sending ends  
At this point, suppose there is an equivalent current  $\dot{I}_{ij}$ , and the current is injected into the  $i$  point, which can cause the same voltage change at the  $i$  point, that is

$$\Delta \dot{U}_{ij} = Z_{ii} \cdot \dot{I}_{ij} \quad (9)$$

Therefore, it can be considered that the effect of the  $j$  point injection current  $\dot{I}_j$  at the  $i$  point can be equivalent to directly injecting the equivalent current  $\dot{I}_{ij}$  at the node- $i$ . Where  $Z_{ij}$  is the mutual impedance between nodes  $i$  and  $j$ ,  $Z_{ii}$  is the self-impedance of node  $i$ . We can obtain equation (10) by equations (8) and (9),

$$\dot{I}_{ij} = \frac{Z_{ij}}{Z_{ii}} \cdot \dot{I}_j \quad (10)$$



**Figure 4.** Node  $j$  injection current is equivalent to the node  $i$

At this point, the point  $j$  injection current  $\dot{I}_j$  in the system generates the AC bus power at point  $i$  can be expressed as

$$S_{ij} = \dot{U}_i \cdot \dot{I}_{ij}^* = \dot{U}_i \cdot \frac{Z_{ij}}{Z_{ii}} \cdot \dot{I}_j^* \quad (11)$$

Among them,  $\dot{U}_i = |\dot{U}_i| \angle \delta_i = U_i \angle \delta_i$  and  $\dot{U}_j = |\dot{U}_j| \angle \delta_j = U_j \angle \delta_j$  are the system bus voltage, the voltage level in the transmission system is so high that can ignore the resistance effect, so that the system impedance is mainly reactance; assuming that the self-impedance and mutual impedance in the system are purely inductive, that is, the impedance phase angle is  $90^\circ$ , according to equation (11) can be reduced to

$$S_{ij} = \left| \frac{Z_{ij}}{Z_{ii}} \right| \cdot \frac{\dot{U}_i}{\dot{U}_j} \cdot \dot{U}_j \cdot \dot{I}_j^* = \left| \frac{Z_{ij}}{Z_{ii}} \right| \cdot \frac{U_i}{U_j} \cdot S_j \angle \delta_{ij} \quad (12)$$

Where  $S_j = P_{dj} - jQ_{dj} = |S_j| \angle \varphi_j$ ,  $\delta_{ij} = \delta_i - \delta_j$ , after simplification we can get

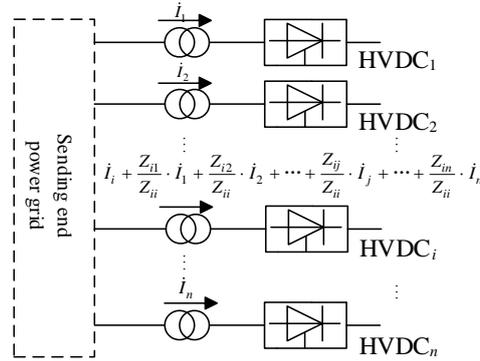
$$\begin{aligned} S_{ij} &= P_{dij} - jQ_{dij} = \left| \frac{Z_{ij}}{Z_{ii}} \right| \cdot \left| \frac{U_i}{U_j} \right| \cdot |S_j| \angle (\varphi_j + \delta_{ij}) \\ &= \left| \frac{Z_{ij}}{Z_{ii}} \right| \cdot \frac{U_i}{U_j} \cdot \left[ |S_j| \cdot \cos(\varphi_j + \delta_{ij}) + j |S_j| \cdot \sin(\varphi_j + \delta_{ij}) \right] \end{aligned} \quad (13)$$

Equation (13) corresponds to the left and right sides, you can get the next two

$$P_{dij} = \left| \frac{Z_{ij}}{Z_{ii}} \right| \cdot \frac{U_i}{U_j} \cdot (P_{dj} \cos \delta_{ij} + Q_{dj} \sin \delta_{ij}) \quad (14)$$

$$Q_{dij} = \left| \frac{Z_{ij}}{Z_{ii}} \right| \cdot \frac{U_i}{U_j} \cdot (Q_{dj} \cos \delta_{ij} - P_{dj} \sin \delta_{ij}) \quad (15)$$

Equation (14) and (15) means in two DCs, the influence of active power and reactive power of one DC on the other when the mutual coupling between DCs is considered.



**Figure 5.** Node n-1 injection current equivalent to the node i

The situation of two DCs can be generalized. When the system contains n DCs, consider the equivalent power of the other n-1 DCs superimposed on the i-th DC converter bus, we can get

$$\tilde{P}_{dij} = \sum_{j=1, j \neq i}^n \left| \frac{Z_{ij}}{Z_{ii}} \right| \cdot \frac{U_i}{U_j} \cdot (P_{dj} \cos \delta_{ij} + Q_{dj} \sin \delta_{ij}) \quad (16)$$

$$\tilde{Q}_{dij} = \sum_{j=1, j \neq i}^n \left| \frac{Z_{ij}}{Z_{ii}} \right| \cdot \frac{U_i}{U_j} \cdot (Q_{dj} \cos \delta_{ij} - P_{dj} \sin \delta_{ij}) \quad (17)$$

From the above derivation, we can know that the coupling effect of other n-1 DCs on the i-th DC can be expressed as the equivalent superposition of its power, thus the total equivalent DC's active power in i-th DC can be expressed as the sum of active power of other n-1 DC and i-th DC self-active power.

$$\begin{aligned} MSSCR_i &= \frac{S_{aci}}{\tilde{P}_{di}} = \frac{S_{aci}}{P_{di} + P_{dij}} \\ &= \frac{S_{aci}}{P_{di} + \sum_{j=1, j \neq i}^n \left| \frac{Z_{ij}}{Z_{ii}} \right| \cdot \frac{U_i}{U_j} \cdot (P_{dj} \cos \delta_{ij} + Q_{dj} \sin \delta_{ij})} \end{aligned} \quad (18)$$

Equation (18) is the general formula for multi-send short-circuit ratio. It can be seen that the influence of other DC on the active power of the i-th DC is not only included in the influence of DC's active power, but also includes other DC's reactive power.

Under normal circumstances, the phase angles of the commutated bus voltages of the DCs in the system are not much different, which can be considered  $\delta_{ij} = 0$ . For further simplification, assuming that the voltage amplitude and phase angle of all commutated bus bars are rated and equal,  $U_i = U_j$ , equations (16) and (17) can be reduced to

$$\tilde{P}_{dij} = \sum_{j=1, j \neq i}^n \left| \frac{Z_{ij}}{Z_{ii}} \right| \cdot P_{dj} \quad (19)$$

$$\tilde{Q}_{dij} = \sum_{j=1, j \neq i}^n \left| \frac{Z_{ij}}{Z_{ii}} \right| \cdot Q_{dj} \quad (20)$$

At this point, the multi-send interaction factor and multi-send short-circuit ratio can also be expressed as

$$MSIF_{j,i} = \frac{\Delta U_j}{\Delta U_i} \approx \left| \frac{Z_{ij}}{Z_{ii}} \right| \quad (21)$$

$$MSSCR_i = \frac{S_{aci}}{P_{di} + \sum_{j=1, j \neq i}^n \left| \frac{Z_{ij}}{Z_{ii}} \right| \cdot P_{dj}} \quad (22)$$

So far, the multi-send short-circuit ratio, MSSCR, under simplified conditions has been derived.

In equation (22), the first term of the denominator of the expression  $P_{di}$  represents the influence of the disturbance at the node  $i$  of the converter station causing the change of the  $i$ -th DC active power to

affect the AC system; and the second term of the denominator  $\sum_{j=1, j \neq i}^n \left| \frac{Z_{ij}}{Z_{ii}} \right| \cdot P_{dj}$  indicates when

disturbance occurs at the converter station  $i$  causes the voltage change of the  $j$ -th DC, which leads to the changes of power in  $j$ -th DC to affect the AC system. The superposition of each item fully considers the degree of influence of each DC, indicating that the disturbance occurs at  $i$ , taking into account the DC-coupling effect on the AC system.

In the concept of MSSCR, the influence of HVDC transmission reactive power compensation is not taken into account, so that the evaluation result obtained is biased optimistic. When the voltage of the commutating bus bar is reduced, the reactive power compensation should increase the reactive power to provide voltage support. However, since the reactive power compensation provides the reactive power and voltage satisfaction relationship  $Q_{fc} = \omega_1 C U^2$ , the reactive power is further reduced at the voltage squared rate when the voltage is lowered, leading to weaker voltage support. So it takes into account this vicious cycle of reactive power compensation devices such as AC filters, and defines it as multi-send effective short-circuit ratio (MSESCR), which has the following expression

$$MSESCR_i = \frac{S_{aci} - Q_{ci}}{\tilde{P}_{di}} = \frac{S_{aci} - Q_{ci}}{P_{di} + \sum_{j=1, j \neq i}^n \left| \frac{Z_{ij}}{Z_{ii}} \right| \cdot P_{dj}} \quad (23)$$

It can be seen from the above derivation process that the influence of the DC system on the AC system is mainly reflected in the change of the DC power level, and the influence of the AC system on the DC system mainly causes the voltage fluctuation of the converter bus through the disturbance. The coupling effect between multiple DCs is also caused by the electrical coupling effect, which has a fluctuation effect on the voltage of the commutation bus, and thus affects the active power of the DC.

#### 4. MSCSCR

When studying the static stability problem of the AC system, it is considered that the power stability margin of the DC system is closely related to the static stability of the AC system. The greater the static reserve in the system, the better the static stability of the system. In the single-infeed DC system shown in Fig.1, when the inverter adopts the  $\gamma$  control, it is assumed that the turn-off angle is constant, and the system filter, reactive power compensation, and transformer tap action are not considered. It is considered that the electromotive force of the AC system is constant. Under the ideal premise of these assumptions, the curve of DC power with DC current is the maximum power curve (MPC) of the DC system. The extreme point on the maximum power curve, which satisfied  $\frac{dP_d}{dI_d} = 0$ , is the maximum

point, that is, maximum available power (MAP), the limit of the active power that the HVDC transmission system can deliver. The larger the value, the better the rated runtime stability. The greater the stability margin, the stronger the system's overload capacity.

When the system is running at the left side of the MAP, it is at the rising edge of the power curve, that is  $\frac{dP_d}{dI_d} > 0$ , the system can keep the power stable. When the system is running at the right side of the

MAP, it is at the falling edge of the power curve, that is  $\frac{dP_d}{dI_d} < 0$ , the system will run in the low-voltage and high-current working conditions, causing static and stable destruction of the AC system, which may cause the power system to oscillate asynchronously, and it is difficult to determine the power stable operation.

Usually in a stronger system, the system equivalent reactance is much smaller than the converter transformer leakage reactance, so the system equivalent reactance can be ignored. At this time, the maximum stable running DC current of the inverter is always around 5.5 times the DC current rating, and the system transmission power is always within the transmission limit, leaving a large margin. However, when the system is weak, its stable operating range will be limited. Therefore, it is important to send out the criticality of the stable operation of the hybrid AC/DC transmission system, that is, the critical value of the multi-send short-circuit ratio.

On the MPC, when the rated operating point ( $I_{dN}$ ,  $P_{dN}$ ) of the system coincides with the MAP ( $I_{dMAP}$ ,  $P_{dmax}$ ), it is said that the multi-send critical short-circuit ratio (MSCSCR) is sent at this time. For the rectifier of the sending end system, the control mode is constant current control. In the initial stage, as the current increases, the angle  $\alpha$  decreases, and when the current increases to a certain extent, the angle  $\alpha$  decreases to a minimum firing angle of  $5^\circ$ . The rectifier control mode is switched to a fixed minimum firing angle control. Therefore, when the current value is small, it is still in constant current control, the operating point of MPC in the rectifier side changes on the curve under different  $\alpha$  angles. When it is switched to the fixed minimum firing angle control, its operating point is move on  $\alpha=5^\circ$  curve. However, the maximum power operating extreme point is always obtained after switching the control mode, that is, always at the maximum power point where  $\alpha$  is  $5^\circ$ .

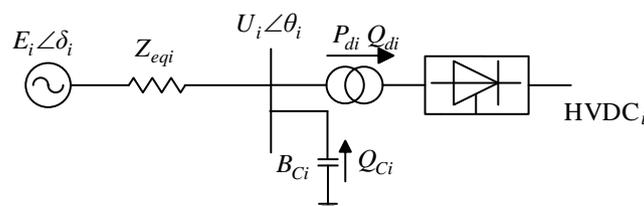
Analogous to the SCR, the commutation bus voltage is selected as the system voltage reference value, and the DC system rated active power is the system power reference value, which can be used to standardize the MSSCR.

$$MSSCR_i = \frac{1}{|Z_{ii}| \cdot P_{di} + \sum_{j=1, j \neq i}^n |Z_{ij}| \cdot P_{dj}} \quad (24)$$

Considering the influence of multiple DC coupling, the system is equivalent to the single sending DC system shown in Fig.6. The effect of other DC on the i-th DC is reflected in the system impedance, and the equivalent impedance can be defined as  $Z_{eqi} = |Z_{ii}| \cdot P_{di} + \sum_{j=1, j \neq i}^n |Z_{ij}| \cdot P_{dj}$ . At this time, similar

to the SCR, the MSSCR can also be expressed as the reciprocal of the equivalent impedance  $\frac{1}{Z_{eqi}}$ , that

is, the critical short-circuit ratio can be equivalent to the critical value of  $\frac{1}{Z_{eqi}}$ .



**Figure 6.** Multi-send hybrid AC/DC transmission system equivalent to single-send HVDC system

For the simplified single-send HVDC transmission system of the multi-send AC/DC system, the rectifier side quasi-steady-state equation of the single HVDC transmission system can be used to describe the operation characteristics of the sending end system. The AC system is in the form of

Thevenin equivalent circuit, and the DC system uses a steady-state average model. Its analytical expression is as shown in equations (25)~(33).

$$P_{di} = C_i U_i^2 [\cos 2\alpha_i - \cos(2\alpha_i + 2\mu_i)] \quad (25)$$

$$Q_{di} = C_i U_i^2 [2\mu_i + \sin 2\alpha_i - \sin(2\alpha_i + 2\mu_i)] \quad (26)$$

$$I_{di} = K_i U_i [\cos \alpha_i - \cos(\alpha_i + \mu_i)] \quad (27)$$

$$U_{di} = \frac{P_{di}}{I_{di}} \quad (28)$$

$$P_{aci} = \frac{1}{|Z_{eqi}|} [U_i^2 \cos \theta_i - E_i U_i \cos(\delta_i + \theta_i)] \quad (29)$$

$$Q_{aci} = \frac{1}{|Z_{eqi}|} [U_i^2 \sin \theta_i - E_i U_i \sin(\delta_i + \theta_i)] \quad (30)$$

$$Q_{ci} = B_{ci} \cdot U_i^2 \quad (31)$$

$$P_{di} - P_{aci} = 0 \quad (32)$$

$$Q_{di} + Q_{aci} - Q_{ci} = 0 \quad (33)$$

Where  $C_i$  and  $K_i$  are converter station equipment parameters, the expression is

$$C_i = \frac{3}{4\pi} \cdot \frac{S_T}{P_{dN}} \cdot \frac{1}{u_k \%} \cdot \frac{1}{\tau^2} \quad \text{and} \quad K_i = \frac{\sqrt{2}}{2} \cdot \frac{S_T}{P_{dN}} \cdot \frac{1}{u_k \%} \cdot \frac{1}{\tau}$$

generally taking 1.1~1.2 times DC rated power  $P_{dN}$ , here assumed  $S_T = 1.15P_{dN}$ ;  $u_k$  is commutation transformer short-circuit impedance, generally take  $15^\circ \sim 20^\circ$ , this paper takes  $u_k = 18^\circ$ ;  $\tau$  is the converter transformer ratio, take 1 under rated operating conditions;  $P_{dN}$  is the rated active power of DC transmission. Typical operating parameters of the sending end system when rated operation and maximum power limit are:  $\alpha_i = 5^\circ$ ,  $\mu_i = 25^\circ$ . Solving the equations, it is possible to obtain a multi-send critical short-circuit ratio of about 1.7 in a multi-send hybrid AC/DC transmission system. When the MSSCR considering other DC-DC effects is less than the critical value of 1.7, the DC power delivered by the system will exceed the limit value, and the system cannot maintain stable operation.

For a single-input DC system and a multi-infeed DC system, the critical short-circuit ratio is 2, which is higher than the multi-infeed critical short-circuit ratio. It can be seen that since the rectifier side generally does not cause commutation failure, the stability threshold of the system on the rectifier side is lower than that on the inverter side, and the strength requirement of the AC system on the transmission side is also reduced. However, there is still a criticality. When the sending end system is too weak, small disturbances may also cause the DC power to exceed the limit, causing system instability.

## 5. Conclusion

In this paper, the static stability evaluation index—SCR and MISCR are studied. On the basis of this, the applicability of the SCR index to the multi-send hybrid AC/DC transmission system is studied, and the MSSCR index is proposed to evaluate the stability of the multi-send hybrid AC/DC transmission system. Through research, the following conclusions can be drawn:

(1) The SCR index has a certain index status. The SCR index applicable to the planned design under rated conditions can characterize the operating characteristics under other conditions.

(2) The general formula of multi-send short-circuit ratio MSSCR index with multi-send interaction factor and multi-send DC coupling is proposed, and a simplified formula considering certain conditions is used for evaluation the strength of the sending end system. In the general formula of MSSCR, it can be seen that other DC's reactive power have an effect on the active power transmission of DC. Enriched the meaning of the SCR.

(3) The definition of the MSCSCR is given. The MSCSCR reference value is obtained under the typical rated operating parameters of the rectifier. According to the research, for the multi-send hybrid AC/DC system, the MSCSCR is about 1.7. When the MSSCR is less than 1.7, the system will not be able to maintain stable operation. In the planning and design, calculation and verification of MSSCR should be carried out to avoid sending more DC access to weaker AC system.

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