Detection Method of HVDC Commutation Failure Using Transient Characteristics of Valve Current

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Abstract. In this study, a detection method of high voltage direct current (HVDC) commutation failure using transient characteristics of valve current to solve the problem of no reliable detection method for HVDC commutation failure in electromagnetic transient simulation is designed. By analyzing the transient characteristics of the valve current in the commutation failure process, the commutation failure criterion is extracted and the detection method has been designed. The detection method includes three parts: detection of valve current extreme point and change rate on its both sides, detection of maximum valve current, and detection of continuous non-zero time of valve current after extreme point. Using the PSCAD/EMTDC electromagnetic transient simulation software, a detection method based on the CIGRE BENCHMARK HVDC model is built up, and the validity and accuracy of the detection method by simulation is verified.

1. Introduction
Commutation failure is one of the most common fault of HVDC transmission systems [1-3], which may reduce equipment life cycle, increases operation and maintenance costs [4], and threatens system operation safety and stability. Fast and accurate detection of commutation failure is an important condition to ensure the safe and stable operation of the system [5]. At present, the criterion and detection of the commutation failure are mainly divided into two types: the measured and the predicted [6]. In general, the measured type of criterion and detection of commutation failure will be more accurate [7]. But based on the comparison of the measured shut-off angle and the limit shut-off angle, due to the existence of a certain blind area, there will be a problem of misjudgment [8]. Aiming at the nature of commutation failure, a commutation failure criterion based on valve current characteristics is proposed in this paper, and a commutation failure detection method using valve current transient characteristics is designed. Based on the model of CIGRE BENCHMARK HVDC, the PSCAD/EMTDC electromagnetic transient simulation software was used to build a commutation failure detection module and simulations were performed. The simulation results show that the method can accurately and quickly detect whether the system commutation fails.

2. Valve Current Characteristic Analysis During HVDC Commutation Failure Occurs
When the two valves of the inverter commutate, if the commutation process fails to complete, or if the valve is planned to be shut down and the blocking capability cannot be restored during the reverse voltage withstand, it will switch back on when the withstand voltage turns positive, that is, the reverse commutation occurs. At the same time, the valve expected to conduct shuts off again, which is called commutation failure [1, 9-11].
As we know, during the commutation and reverse commutation, the valve current is reduced to zero and maintained for a short period of time (that is, shut-off angle $\gamma$)[12]. In severe cases, it even doesn’t fall to zero. But when the valve starts to withstand positive voltage, that is, the valve is turned on again or when the next valve starts to withstand the reverse voltage, the commutation process from the valve to the next valve does not end, causing the next valve to start blocking and the current on the first valve to increase again. When the valve connected to the same phase in another half bridge is turned on, due to the short circuit on the DC side, the increase amplitude and increase rate of the current on the valve is increased again.

No matter in simulations or actual projects, the inverter trigger angle is normally 140° during normal operation, while the commutation angle is about 25°, and the turn-off angle is about 15°. Once the fault causes the DC current to increase, the commutation angle will increase substantially at the same time, and the shut-off angle will be reduced. Once it is smaller than the angle corresponding to the minimum time for the valve to recover the blocking capacity, ie the minimum shut-off angle, the commutation will fail. The minimum turn-off angle in real projects is about 7°, which is equivalent to only 0.39 ms, as shown in figure 1(a). In addition, in most cases, reverse commutation occurs when the voltage crossing zero occurs and the commutation process is not completed, as shown in figure 1(b).

3. Commutation Failure Detection Method Using Valve Current Characteristics

3.1. Commutation Failure Criterion

In summary, the essential process of commutation failure is the reverse commutation. It is very simple and accurate to judge whether the system commutation fails through the transient characteristics of the valve current waveform such as the valve current amplitude and its change rate, or whether there is an extreme point. Therefore, the valve current can essentially reflect whether the system commutation fails, and because of its outstanding features of commutation failure, it is very suitable for the detection of commutation failure. Therefore, based on the transient characteristics of the valve current at the time of commutation failure, a criterion for commutation failure is proposed:

- The valve current waveform has a minimum point, and the rate of decay or increase before or after the minimum value reaches a certain value;
- The maximum value of the valve current after the minimum point is greater than the normal operating current;
- The non-zero duration of the valve current after the minimum point is greater than the normal continuous conduction time of one of the converter valves.

If the above three conditions are satisfied at the same time, it is determined that commutation failure has occurred.

3.2. Commutation Failure Detection Method

(1) Detection of valve current extreme point and change rate on its both sides
Mainly using the derivative of the valve current, the logic of figure 2 is to detect whether there is an extreme point, and to judge whether the maximum decay rate before reaching the minimum point is greater than $S_N$ and the maximum increase rate after the minimum point is greater than $S_P$. When the output signal $L_{MIN,CF}$ is high level 1, there is an extreme point, otherwise it does not exist.

(2) Detection maximum valve current

The logic of figure 3 is to check whether the maximum value of the valve current is greater than the maximum current $I_{V,NOM}$ when the converter valve is normally turned on. When the output signal $L_{MAX,CF}$ is high level 1, there is over current, otherwise it does not exist.

(3) Detection of continuous non-zero time of valve current after extreme point

The logic of figure 4 is to measure the time that valve current continues for non-zero after the extreme point, and it is judged whether the time is greater than the normal time $T_{V,NOM}$. When the output signal $L_{TC,CF}$ is high level 1, it indicates that the valve current duration after the extreme point meets the commutation failure criterion, otherwise commutation failure does not occur.

(4) Commutation failure detection

As shown in figure 5, the signals output by the above three condition detection logics are output by the AND logic and are retained by the MAX HOLD as the final $i$-th valve current commutation failure detection output signal for the 12-pulse converter. $i$=D1, D2, ..., D6, Y1, Y2, ..., Y6. If there is a valve
current commutation failure detection output is high level 1, the commutation fails, otherwise commutation failure occurs.

4. Simulation
Based on the CIGRE BENCHMARK HVDC standard test model (shown in figure 6), this paper sets up a commutation failure detection module in the electromagnetic transient simulation software PSCAD/EMTDC and sets different faults on the AC bus of the inverter side to verify the feasibility of the proposed commutation failure detection method.

The commutation failure detection module parameter settings are shown in table 1:

Table 1. Parameters of commutation failure detection module.

| Parameter | T1 / (s) | SN / (kA/s) | SP / (kA/s) | IV_NOM / (kA) | TV_NOM / (s) |
|-----------|----------|-------------|-------------|---------------|-------------|
| Value     | 0.001    | 0.5         | 0.5         | 2.2           | 0.008       |

To verify the accuracy of proposed commutation failure detection method using the characteristics of valve current, the typical three phase faults is selected as an example for analysis.

4.1. Three phase short circuit fault in AC bus at inverter side
The fault starting time is 3.0s, and the duration is 100ms. The short-circuit grounding inductance taken as 0.4H. The simulation results are shown in figure 7.

Figure 7. Waveforms of AC voltage at inverter side, DC voltage and valve current under three phase short-circuit fault.
As can be seen from figure 7, after three-phase short-circuit fault occurs in the 3.0 s on the inverter side AC bus, the commutation from the valve VY3 to the valve VY5 fails at the first time \( t_1 = 3.0035 \) s, and when the valve VY6 is turned on at \( t_2 = 3.0048 \) s, the inverter side DC voltage drops by about half. At \( t_3 = 3.0058 \) s, the commutation failure occurs when the valve VD3 commutates to the valve VD5, and when the valve VD6 is turned on after \( t_4 = 3.0077 \) s, the DC side short circuit occurs, so that the DC voltage on the inverter side drops to zero. And it continues until the valve VY6 fails to commutate to the valve VY2 \( (t_5 = 3.0138 \text{ s}), \) that is, the time valve VD6 turns off \( (t_6 = 3.0176 \text{ s}) \). The commutation failure detection result using the characteristics of valve current is shown in figure 8, and the detected commutation failure order is: valve VY3, valve VD3, and valve VY6. Obviously, it is consistent with the above analysis. In addition, the deviation between the detection result and the switching phase is shown in table 2:

**Table 2. Time deviations of detection results during commutation failure occurs under three phase short-circuit fault.**

| Deviation | \( t_{Y3-Y5} / \text{(s)} \) | \( t_{Y3-D5} / \text{(s)} \) | \( t_{Y6-Y5} / \text{(s)} \) |
| --- | --- | --- | --- |
| Value | 0.0062 | 0.0055 | 0.0052 |

From table 2, we can see that the reaction time of the proposed commutation failure detection method under three-phase fault on AC bus of the inverter side is only 5 ~ 6ms, indicating that it can quickly provide support for the control and the action of protection system. Other fault types have also been simulated and the feasibility and effectiveness of the method have been verified. Due to space limitations, further details are not listed.

5. Conclusion
A commutation failure criterion and detection method using valve current characteristics was designed in this paper. This method is simulated by selecting three phase fault on the AC side of the inverter to verify its feasibility. It is proved that this method can effectively, reliably and quickly detect commutation failures. However, it is not limited to three-phase fault condition, and it is still valid under the other fault conditions. It can provide reference and support for commutation failure simulation research work.

6. References
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