Commutation failure detection of DC system based on S transform entropy

Zhi-wen Fang

School of Electronic, Electrical Engineering and Physics, Fujian University of Technology, Fuzhou, Fujian, 350118, China

*Corresponding author’s e-mail: 2191971053@qq.com

Abstract. The failure of commutation will cause the abrupt change of the operating parameters of the DC system. In this paper, the mechanism and physical process of commutation failure are analyzed. In view of the changing characteristics of inverter side valve current and DC current in the case of commutation failure, two kinds of S transform entropy are introduced into the detection of commutation failure of DC system in combination with S transform entropy's excellent signal change feature recognition ability. In addition, the detection performance of the two s-transform entropies is fully considered in the case of no commutation failure, critical commutation failure and commutation failure. The simulation results based on PSCAD/EMTDC preliminarily verify the validity and accuracy of the two kinds of S transform entropy in dc system fault detection, which provides a basis for the further application of S transform entropy in dc system fault detection field.

1. Introduction
As an irreplaceable and important part of the application field of the power industry in the 21st century, HVDC transmission has always been an indispensable force in supporting the large-capacity and long-distance transmission of energy in my country. However, the DC projects under construction and put into operation in my country basically use the grid commutation converter, that is, the converter valve adopts the DC transmission technology of thyristor, and the phenomenon of DC system commutation failure, which is strongly related to the AC system fault, is very common [1]. From 2006 to 2007 alone, the commutation failures of China Southern Power Grid Tianguang DC caused by AC system failures reached 14 times [1]. For this reason, adopting an effective and reliable detection method to quickly and accurately detect the commutation failure of the DC system, and on this basis, give full play to the role of the power grid security defense system, which is undoubtedly important for ensuring the safe and stable operation of the AC-DC interconnection system. It is of great significance that the actual application background of the detection of DC system commutation failure is becoming clearer and clearer.

There are many theories and methods of power system fault detection, mainly including: information entropy theory, wavelet transform theory, S transform theory, mathematical morphology. Combining different theories and methods can also obtain a new fault detection and identification algorithm, Achieve complementary advantages and comprehensively improve the effectiveness and accuracy of detection. Reference [2] proposes the method of using wavelet time entropy to achieve fast and accurate fault detection, analyzes and compares the wavelet time entropy distribution characteristics of signal components in different frequency bands under the conditions of ground fault, lightning strike and noise, and gives a reliable distinction between faults and lightning strikes and
noise. criterion. Reference [3] extracts the high-frequency transient current signal by using the mathematical shape gradient. On the basis of comparing the characteristics of the transient signal formed by the excitation inrush current and the fault current, a new transformer protection scheme is proposed. In recent years, as a new signal processing method, S transform has been recognized by the majority of researchers for its application effect in power system. Reference [4] combines S-transform, singular value decomposition and information entropy theory to identify transient and permanent faults of ultra-high voltage long transmission lines with shunt reactors, and has achieved good results. Reference [5] uses the high-resolution time-frequency characteristics and information entropy of the S-transform to characterize the system state, and combines the two to define the S-transform singular entropy and the S-transform energy entropy, and gives its algorithm, revealing the characterization mechanism of the two S-transform entropies for system faults, and the analysis of power line fault signals based on PSCAD/EMTDC software simulation shows that the two S-transform entropies have high sensitivity to system changes and are not disturbed by noise, and can effectively detect power system failures, but the simulation results only apply to AC systems. In this paper, the occurrence mechanism and physical process of commutation failure are firstly analyzed. According to the change characteristics of the valve current and DC current on the inverter side under the condition of commutation failure, the two S-transform entropies proposed in the reference [5] are introduced into the DC system, using for commutation failure detection.

2. Occurrence mechanism and physical process of commutation failure

Commutation failure is one of the most common faults on the inverter side of HVDC transmission systems, and is closely related to short-circuit faults in the AC system. According to the definition of commutation failure, if the valve current ending time is later than the corresponding AC line voltage zero-crossing time, the valve is under the action of reverse voltage for too short time, and the blocking capacity is not fully recovered. Afterwards, it will bear the forward voltage, and at this time, it will be turned on again without triggering, resulting in a commutation failure failure. The fundamental reason for the commutation failure is that the thyristor device used in the DC system is a semi-controllable device, and its reliable turn-off must rely on the AC system at the receiving end to provide a strong enough voltage support to achieve carrier recombination and PN junction barrier layer. Establish. If the short-circuit fault occurs in the AC system and the commutation voltage is lower than the critical value, the DC system is prone to commutation failure. During normal operation, the schematic diagram of the commutation process of the inverter is shown in figure 1. The thyristors arranged in the specified order are turned on in sequence according to the specified order during the commutation process to realize the continuous "cutting" of the AC voltage, which converts AC voltage to DC voltage.

![Figure 1. The commutation process of DC system during normal operation.](image)

Figure 2 and figure 3 show the schematic diagrams of the Cigre HVDC standard test system and the high-voltage bridge of the inverter-side converter of the DC system respectively used in the simulation and verification in this paper.
Figure 2. Cigre HVDC Standard Test System.

Figure 3 shows the schematic diagram of the high-voltage bridge of the inverter side converter of the DC system. The order of the six valves from top to bottom is v4, v6, v2, v1, v3, v5, of which the valves v4, v6, and v2 are the upper row valves, valves v1, v3, v5 are the lower row valves; the conduction order of the 6 valves is different, which are v1, v2, v3, v4, v5, v6. When the valve v1 starts to commutate to the valve v3 (the valve v1 starts to withdraw, the valve v3 starts to conduct, the two processes are carried out at the same time but it takes a while to complete), it is assumed that a short circuit fault occurs in the AC system at this time, causing the valve v1 to commutate to the valve v3. If it fails, the DC voltage of the inverter on the inverter side will gradually decrease, and the DC current will increase. When valve v2 is commutated to valve v4, it is obvious that valve v1 and valve v4 will form a bypass pair, which will cause the entire converter high-voltage bridge to be in a short-circuit state, and the DC current will have a sudden change at valve v1 and valve v4. Therefore, during the commutation failure, the speed of the DC current at valve v1 and valve v4 changes significantly, and the DC current can be regarded as a sudden change signal.

3. Two definitions of S-transform entropy

3.1. S-transform energy entropy

After S-transformation, a modulo time-frequency matrix D is obtained, which can be processed into a probability distribution sequence, and the entropy value calculated from these modulo values reflects the sparsity of the modulo value matrix, that is, the order of the signal probability distribution. Reference [5] defines the energy spectrum of the signal at different frequencies k and different times j:

\[ E_{ij} = |D_{ij}|^2, \quad E_k = \sum_{j=1}^{N} E_{kj} \]  \( (1) \)

According to the above two formulas, the S-transform energy entropy can be defined, denoted as SEE, and the mathematical model expression is:
\[
SEE = -\sum_k P_k \ln P_k, \quad P_k = E_k / E, \quad E = \sum_{k=1}^K E_k
\]  

(2)

Among them, \(E\) represents the total energy of the signal; \(E_k\) represents the sum of the energy at all times at the frequency \(k\).

### 3.2. S-transform singular entropy

The establishment of the singular entropy of the S transform needs to refer to the singular decomposition theory of the signal, and the modular time-frequency matrix \(D\) is decomposed to obtain a diagonal matrix \(\Lambda\), and the main diagonal element \(\lambda_i (i=1,2,...,r)\) of \(\Lambda\) is non-negative, in descending order. These diagonal elements are the singular values of the modulo time-frequency matrix \(D\). Define the S-transform singular entropy, denoted as \(SSE\), and the mathematical model expression is:

\[
SSE = -\sum_{i=1}^r \left[ \frac{\lambda_i}{\sum_j \lambda_j} \right] \ln \left( \frac{\lambda_i}{\sum_j \lambda_j} \right)
\]  

(3)

The singular entropy of the S-transform of the singular decomposition theory of the reference signal directly reflects the uncertainty of the energy distribution of the analyzed signal in the time-frequency space.

### 4. Detection of commutation failure of DC system Appendices

This paper uses the Cigre HVDC standard test system in PSCAD/EMTDC to set 3 different operating conditions: no commutation failure, critical commutation failure, commutation failure, extract the DC current on the inverter side, and calculate the two kinds of S-transform entropy were plotted into a graph, and the detection performance of the two kinds of S-transform entropy was tested and compared. According to engineering experience, when the turn-off angle \(\gamma\) of the inverter side is less than \(7.2^\circ\), commutation failure occurs. When the turn-off angle \(\gamma\) on the inverter side is equal to \(7.2^\circ\), a critical commutation failure occurs.

#### 4.1. Normal operation without commutation failure

During normal operation, the DC current is about \(2\)\(\text{kA}\), and the S-transform energy entropy and S-transform singular entropy of the DC current are very small at this time. The simulation results are as shown, the maximum value of S-transform energy entropy is about \(0.006\) and is relatively stable, and the maximum value of S-transform singular entropy is about \(0.002738\). Due to the ripple in the DC current during steady-state operation, the values of S-transform energy entropy and S-transform singular entropy vary within a certain range, but the values of the two S-transform entropies are very small, and both are lower than \(0.01\).
4.2. Critical commutation failure
In the Cigre HVDC standard test system, when the commutation bus on the inverter side is grounded through a 150ohm transition resistance within 2 seconds, and the fault duration is 0.05 seconds, the turn-off angle $\gamma$ of the inverter side is 7.2°. What happens is a critical commutation failure. Extract the DC current on the inverter side, calculate the two S-transform entropies of the DC current and draw them into a graph. The results are as follows:
In the case of critical commutation failure, the DC current on the inverter side begins to increase but does not exceed 2.4kA, and the S-transform energy entropy and S-transform singular entropy are also larger than those in normal operation. However, the maximum value of S-transform energy entropy does not exceed 0.1, and the maximum value of S-transform singular entropy does not exceed 0.02.

4.3. Commutation failure occurred
In the Cigre HVDC standard test system, when the commutation bus on the inverter side is grounded through a transition resistance of 0ohm within 2 seconds, and the fault duration is 0.05 seconds, the turn-off angle $\gamma$ of the inverter side drops to 0. What happens is that the commutation fails. Extract the DC current on the inverter side, calculate the two S-transform entropies of the DC current and draw them into a graph. The results are as follows:

In the case of commutation failure, the DC current on the inverter side begins to increase and exceeds 5kA, and the S-transform energy entropy and S-transform singular entropy are also larger than those in the case of critical commutation failure. The maximum value of S-transform energy entropy reaches 3, and the maximum value of S-transform singular entropy does not exceed 0.5. It can be seen that the S-transform energy entropy and S-transform singular entropy values in the case of commutation failure are much larger than the S-transform energy entropy and S-transform singular entropy values in the absence of commutation failure and critical commutation failure.

5. Conclusion
In this paper, two kinds of S-transform entropy are introduced into the detection of commutation failure of DC system, and the detection performance of the two kinds of S-transform entropy is fully considered in the three cases of no commutation failure, critical commutation failure, and commutation failure. The simulation results preliminarily verify that the two S-transform entropies are effective in fault detection of DC systems, and have certain practical application value.
References
[1] Zexiang, C. (2020) Fault Transients of HVDC Transmission Systems and Its Impacts to Protective Relaying Dynamics. Science Press, The Beijing.
[2] Wang, S., Bi, T.S., Jia, K. (2016) Wavelet Entropy Based Single Pole Grounding Fault Detection Approach for MMC-HVDC Overhead Lines. J. Power System Technology.2016, 40(7): 2179-2185.
[3] Ma, J., Xu, Y., Wang, Z.P. (2006) Power transformer protection based on transient data using mathematical morphology. J. Proceedings of the CSEE,2006,26(6):19-23.
[4] Zhao, Y., Gao, L., Wang, Y. (2010) A method to recognize fault symbol for adaptive single phase reclosure based on energy entropy of singular value from S-transform. J. Power System Technology, 2010, 34(12): 209-213.
[5] Tao, W.Q., Xia, Y., Lu, D.K. (2016) Study of S-transform entropy theory and its application in fault detection of electric power system. J. Journal of Hefei University of Technology(Natural Science),2016,39(1): 40-45.