Postprint: Case Analysis of UHVDC Valve Group Deblocking Failure Caused by Hall Sensor Fault

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Abstract

Hall sensors are unique open/close position sensing elements for bypass circuit breakers in ultra-high voltage direct current (UHVDC) transmission systems, and play a critical role in the process of deblocking another valve group while a single valve group is operating in the same pole. This paper analyzes a case of unsuccessful valve group deblocking caused by Hall sensor failure, and proposes an improvement recommendation for periodic calibration of Hall sensors.

Full Text

Case Analysis of UHVDC Valve Group Deblock Failure Caused by Hall Sensor Fault

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Abstract

The Hall sensor serves as the specific position-sensing element for the bypass switch in ultra-high voltage direct current (UHVDC) transmission systems, playing a critical role during the deblocking process of one valve group while another valve group operates on the same pole. This paper analyzes a case of valve group deblock failure caused by Hall sensor malfunction and proposes improved recommendations for regular calibration of Hall sensors.

Keywords: UHVDC, Hall sensor, bypass switch, deblock failure

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1 Introduction

The Yun-Guang UHVDC transmission project represents the world' s first ±800 kV UHVDC transmission system, featuring a dual-pole, four-valve-group design. Each pole consists of two series-connected 12-pulse valve groups, and independent operation of individual valve groups is achieved through the switching of bypass switches connected in parallel with the valve groups.

Since the bypass switch must interrupt DC current with a rated voltage of 400 kV and rated current of 3,150 A, neither active nor passive DC circuit breakers can directly break such current. This requires coordination with the converter valve group to achieve current transfer. During actual operation of the Yun-Guang UHVDC project, a fault occurred where the valve group could not be deblocked due to a bypass switch position sensor failure. This paper analyzes this fault and proposes improvements to preventive testing procedures for bypass switches.

2 Fault Case Description

On April 2, 2014, at 17:46, a ±800 kV converter station attempted sequential deblocking of the Pole II high-end valve group while the low-end valve group was operating. After the Pole II high-end valve group bypass switch 0820 (hereinafter referred to as 0820) opened, the Pole II high-end valve group protection (82BPS) activated, initiating DC emergency switch-off (ESOF) control for the high-end valve group. The 0820 switch subsequently reclosed, resulting in unsuccessful sequential deblocking of the Pole II high-end valve group.

The DC field bypass switch (BPS) is equipped with bypass switch protection Stage I (82BPS-I). The protection action logic is as follows: Stage I protection operates when $|IdBPS| > 0.07$ pu (219 A) AND (Open Bypass Switch Request = 1 OR Bypass Switch Checkback = 0), with a time delay T = 50 ms. In other words, when the valve group protection receives a BPS opening command from the group control system (Group Control_Bypass Switch_Open_Request) or the BPS is in the open position, and the current through the BPS exceeds 219 A, the bypass switch protection Stage I (82BPS-I) operates after a 50 ms delay to close the BPS.

According to the waveform in [Figure 1: see original paper], at 17:46:07.03002, the valve group protection (=22RG11+R1) (hereinafter referred to as group protection) received the command to open bypass switch 0820 from the group control system. At this moment, the digital signal "22RG11+R1/GC_BPS_OPEN_REQ" (i.e., the "Open Bypass Switch Request" signal) within the group protection software changed abruptly from "0" to "1," and this command persisted for approximately 100 ms.

After receiving the 0820 opening command, the group protection enabled bypass switch protection Stage I (82BPS-I) following a 15 ms delay. At 17:46:07.0586, the digital signal "22RG11+R1/GDCP_BPS_Checkback" (i.e., the "Bypass Switch Checkback" signal, hereinafter referred to as the "Checkback" signal) within the group protection software changed from "1" to "0," as shown by the red digital signal trace in [Figure 2: see original paper].

During the period when group protection was enabled, the IdBPS current increased from 3,146 A to 3,750 A, continuously satisfying the $|IdBPS| > 0.07$ pu (219 A) criterion. After a 50 ms delay, at 17:46:07.096, the group protection issued a command to close 0820, as indicated by the green digital signal trace in [Figure 3: see original paper] showing the "22RG11+R1/CLS_BS_REQ" signal.

Based on the above analysis, the bypass switch protection Stage I (82BPS-I) operated correctly.

3 Fault Analysis and Treatment

For UHVDC transmission systems, when one valve group of a pole is operating and the second valve group is being deblocked, the bypass switch of the second valve group must be opened. Due to the limited arc-extinguishing capability of the bypass switch itself, the deblocking process must rely on precise control by the valve group control system to coordinate the converter valve firing sequence with the bypass switch opening timing. This ensures that current through the bypass switch is minimized when it opens, enabling reliable current transfer to the converter valve (referred to as forced phase shifting).

To achieve tight coordination between bypass switch control and valve firing sequence, a switch position detection unit is installed in the valve group bypass switch. This unit transmits a 4–20 mA analog signal 10 ms before the switch mechanism completes its opening or closing operation, providing advance notification to the valve group control system to release the converter valve firing pulses. The specific principle is as follows: When one valve group is already in the deblocked state and the system initiates deblocking of the second valve group, it first issues a command to open the bypass switch without immediately deblocking the converter valve. Upon receiving the opening command, the bypass switch activates its operating mechanism. At 40 ms into the switch operation, the position detection unit sends the corresponding analog signal to the valve group control system, indicating that the switch will open in 10 ms. Upon receiving this analog signal, the control system immediately releases firing pulses while maintaining a firing angle of 70°. Since the DC side of the valve group to be deblocked is short-circuited by the bypass switch, the current generated by the deblocking valve group flows opposite to the current from the other valve group. Testing has shown that the inrush current generated 10 ms after deblocking with a 70° firing angle can transfer current from the bypass switch to the converter valve, reducing the current through the bypass switch to a level within its arc-extinguishing capability. The valve group bypass switch reliably opens 10 ms after converter valve deblocking, and the control system then delays an additional 6 ms before switching the firing angle from 70° to normal operation, depending on whether it is on the rectifier or inverter side, thus successfully deblocking the second valve group. The group control system software logic is shown in [Figure 4: see original paper].

As shown in [Figure 5: see original paper], after the Pole II high-end valve group initiated the deblocking sequence and issued the 0820 opening command, the group control system failed to receive the 0820 open position signal within 65 ms (the time interval from when group protection received the 0820 opening command to when bypass switch protection Stage I operated is 15 ms + 50 ms = 65 ms). This prevented the group control system from initiating the forced phase shifting process in time, resulting in the current through 0820 remaining above 3,125 A and continuously satisfying the protection criterion. Consequently, the bypass switch protection Stage I operated to reclose 0820 and initiate valve group ESOF. Additionally, [Figure 5: see original paper] shows that the 0820 open position signal was delayed by approximately 143 ms before reaching the group control system, whereas under normal conditions, the bypass switch open position signal should be fed back to the group control system about 40 ms after the deblocking command is issued.

Since the current through 0820 was not extinguished, analysis revealed that the bypass switch's position transmitter was not functioning properly. By comparing the delay times of the group protection "Checkback" signal and the group control system "CLOSED" signal, it was determined that the position transmitter in the bypass switch mechanism box was not operating correctly. Instead, the group control system was receiving position signals from the measurement and control device via fieldbus. Therefore, the preliminary diagnosis identified a problem with the position transmitter sending signals to the group control system.

Because the position signal must be sent to the group control system 10 ms before the bypass switch completes its opening operation, conventional breaker auxiliary contacts cannot be used for this signal transmission. The position signal received by the group control system is actually provided by a Hall sensor mounted on the circuit breaker.

Hall sensors are common sensing devices with unique magnetic field detection capabilities, featuring simple circuit structures, low noise, compact size, wide dynamic range, broad frequency response, and long service life. They can use magnetic fields as information carriers to convert non-electrical, non-magnetic physical quantities such as displacement, force, acceleration, angle, angular velocity, and rotational speed into electrical signals. These characteristics make Hall sensors particularly suitable for non-contact position detection of bypass switches before they fully open or close. When the circuit breaker operates, the permalloy sensing head fixed on the breaker crank arm moves accordingly, as shown in [Figure 6: see original paper].

Palloy’ s key characteristic is its extremely high magnetic permeability in weak magnetic fields. When it rapidly passes over the Hall sensor element (see arrow in [Figure 6: see original paper]), the Hall sensor generates a 4–20 mA analog current signal. By adjusting the installation position of the sensing head, any travel signal reflecting the breaker’ s position can be transmitted.

After replacing the Hall sensor element, remote opening and closing operations were performed again, with waveforms recorded during the process. Analysis of the recorded waveforms confirmed that the timing coordination between 0820 and the control protection system met program requirements, as shown in [Figure 7: see original paper]. Following replacement, the valve group was successfully deblocked.

4 Conclusion

This case analysis of unsuccessful valve group deblocking demonstrates that the bypass switch position transmitter plays a crucial role in the control system when one valve group is operating on a pole and the second valve group is being deblocked. Currently, various circuit breaker testing procedures do not include inspection requirements for this type of Hall sensor-based position transmitter. Conventional preventive test items only measure the opening and closing time of the breaker contacts without requiring measurement of the signal transmission timing. Therefore, it is recommended that when conducting preventive tests on bypass switches to measure opening and closing times, the position signal transmission time should also be measured to ensure proper output of open and close position signals.

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Note: Figure translations are in progress. See original paper for figures.