Research on hidden dangers of oil-flow relay in HVDC converter transformer

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Abstract. HVDC converter transformer oil-flow relay plays an important role in realizing non-power protection of converter transformer on-load tap changer, which can act accurately and directly affect the safe and stable operation of the whole HVDC program as well as the converter transformer itself. In this paper, the research revolves around the hidden dangers of HVDC converter transformer and its identification. The paper begins with the analysis of the converter transformer operating principles of two German companies: MR and EMB. Then, the current application status and related inspection requirements of oil-flow relay are expounded. Finally, pertinent hidden danger identification and modification schemes are provided based on analysis of the danger in actual operation of oil-flow relay and its causes. The feasibility and effectiveness of the scheme are verified by the actual operation on site.

1. Introduction
With the rapid development of Chinese power grid in the past two decades, and the proposal and implementation of the concept of the global energy Internet, large-scale and long-distance power transmission projects based on HVDC technology have been planned, newly built, and put into operation nationwide. It has been applied to the interconnection projects of regional power grids. Compared with traditional AC transmission, the HVDC system has many decided advantages [1-3], and has gradually become a vital and indispensable part of Chinese power grid. Its operating status is directly related to the safety and stability of the entire power grid.

HVDC converter transformer oil flow relay is a non-electrical protection device used for on-load voltage regulation switches of converter transformers. The flow rate of insulating oil is used as the only way to judge whether the protection is exported. Condition, and the consequence of the action is DC pole blocking. Therefore, the correctness of the oil flow relay action is the basic requirement to ensure the safe and stable operation of the entire HVDC project. But for a long time, my country's power grid has not paid enough attention to the operation and maintenance of oil flow relays. On the one hand, it has not issued targeted inspection procedures. At present, it mainly refers to the "DLT 540 Gas Relay Inspection Regulations" [4]; on the other hand, it is manifested in the failure of regular inspections as required, and even the phenomenon of not carrying out inspections at all. Correspondingly, on May 29, 2015, the Mujia Converter Station and the Yimin Converter Station had misoperation of the oil flow relay. The two incidents directly caused the DC outage and caused serious impacts.

Therefore, this paper compares and analyzes the working principle of commonly used oil flow relays in converter transformers, expounds the current application status of oil flow relays and related inspection requirements, based on the hidden dangers and causes of oil flow relays in practical
applications. Based on the analysis, a targeted hidden danger investigation and transformation plan was put forward. The feasibility and effectiveness of the scheme were verified by the actual operating conditions on site.

2. Analysis of the working principle of oil flow relay

Nowadays, within the scope of the State Grid, the HVDC converter transformer oil flow relay produced by MR and EMB in Germany is the most widely used. Therefore, it is necessary to compare and analyze its structure and working principles.

2.1. MR oil flow relay structure and working principle

As shown in Figure 1, MR oil flow relay is mainly composed of mechanical and electrical parts. The key components of the mechanical transmission parts include: fixed bracket, attracting magnet, reed switch, reed switch fixing clip, baffle limit screw, relay baffle action instructions, etc.

Under normal circumstances, the oil flow relay baffle drives the attracting magnet in the vertical position, the reed switch contact 1 is kept in position by the attraction force of the attracting magnet, and the reed switch contacts 2 and 3 are normally open contacts, which are maintained in normal conditions and the quintile.

Under fault circumstances, the baffle is pushed by the oil flow, and the thrust of the oil flow on the baffle exceeds the attraction force of the baffle magnet, the baffle moves from the vertical position. After the baffle is in contact with the limit screw, the reed tube contact 2, 3 is attracted by the attraction force of the attraction magnet, contact 1 loses the attraction force of the attraction magnet, the contact is attracted, and the relay sends out a trip signal, as shown in Figure 2 and Figure 3.

2.2. EMB oil flow relay structure and operating principle

As shown in Figure 4, the EMB oil flow relay is mainly composed of mechanical and electrical parts. The key components of the mechanical transmission part include: fixed brackets, baffles, baffle limit magnets, attracting magnets and reed switches.
Under normal circumstances, the oil flow relay baffle is attracted to a fixed position by a limit magnet, which can prevent the baffle from rotating or moving.

![Figure 4. EMB oil-flow relay internal structure diagram 1.](image1)

Under fault circumstances, the baffle is pushed by the oil flow. After the thrust of the oil flow on the baffle exceeds the attraction force of the limit magnet, the baffle rotates around the shaft and drives the counterweight and the attraction magnet to rotate around the shaft together. When the magnet on the baffle is close to the dry reed contact, the dry reed contact is attracted and the relay sends out a trip signal, as shown in Figure 5 and Figure 6.

![Figure 5. EMB oil-flow relay internal structure diagram 2.](image2)  
![Figure 6. EMB oil-flow relay action principle diagram.](image3)

It can be seen from 1.1 and 1.2 that the oil flow relays of German EMB and MR all use the movement of the baffle to determine whether the protection is exported. The former has a simple structure and the number of dry reed contacts is optional; the latter directly adopts the form of three contacts, each with each Advantage.

3. Application status and inspection requirements of oil flow relay

3.1. Application status

The HVDC project put into operation in the early stage of Chinese power grid mainly adopted by ABB and Siemens technology, and main part is imported equipment. Although the degree of localization has greatly increased in recent years, the oil flow transformers used in converter transformers are still mainly imported. Adopt the products of German EMB Company and German MR Company. Taking Hubei Power Grid as an example, there are 5 ±500kV HVDC project sending-end converter stations in its territory, and a total of 119 converter and variable oil flow relays are produced by German EMB company [5].

At present, the oil flow relay of German EMB Company can provide three kinds of structure forms: single contact, double contact, and three contact. Among them, the single contact only provides one trip signal channel, which has been eliminated by the market; the double contact can provide two independent trip signal channels, and can be configured in parallel or series; the three contacts can provide three independent trip signal channels. The "two out of three" configurations can further improve the reliability of the oil flow relay, and has become the first choice in the market.
The oil flow relay of the German MR company directly adopts the three-contact form, which can provide three independent trip signal channels, and further improve the operation reliability of the oil flow relay through the "three out of three" configurations.

3.2. Inspection requirements

In terms of inspection standards, the current standards at all levels in my country do not involve specific inspection procedures for converter and variable oil flow relays. The inspection work for oil flow relays is currently carried out with reference to the national power industry standard "DLT 540 Gas Relay Inspection Regulations".

The requirements for the inspection cycle are as follows:
(1) Before the installation of relay;
(2) The inspection period generally does not exceed 5 years;
(3) Conduct relay inspection in conjunction with transformer overhaul;
(4) When the relay malfunctions, refuses to operate, or after maintenance, if necessary.

The inspection is mainly carried out from the following aspects:
(1) Visual inspection;
(2) Dielectric strength test;
(3) Tightness;
(4) Velocity value;
(5) Gas volume value;
(6) Waterproof performance test;
(7) Earthquake resistance;
(8) Reverse oil flow test;
(9) Dry reed contact test.

In terms of power grid requirements, the State Grid Corporation of China began in 2011 to carry out "non-electricity protection 'two out of three'" transformation on the converter and variable oil flow relays of the state grid. Even if the oil flow relay equipped with three contacts is used, through the "two out of three" logic judgment, the risk of DC outage caused by the oil flow relay's misoperation is reduced.

The "two out of three" logic of the oil flow relay is shown in Figure 7.

![Figure 7. "Two out of three" logic of oil-flow relay.](image_url)

4. Investigation and Reformation of Hidden Dangers of Oil Flow Relay

With the large-scale promotion and application of HVDC technology in my country's power grids in the past two decades, the application of oil flow relays has long been caused by unsystematic, inadequate, and inadequate operation and maintenance of converter and variable oil flow relays. Hidden dangers began to be gradually exposed [6-9]. A recent typical case is the misoperation of the oil flow relay that occurred successively at Mujia Converter Station on May 29, 2015 and Yimin Converter Station on June 5, which directly led to DC outages.
The converter transformer of the Mujia converter station uses the oil flow relay of the German MR company. The cause of the fault is that the magnet spacing is too large and the attracting force is too small. The vibration and oil flow surging during the charging of the converter cause the oil flow relay to malfunction. The converter transformer of the Yimin converter station uses the oil flow relay of the German EMB company. The cause of the fault is the fragmentation of the limit magnet, the magnet suction is greatly reduced, and the oil flow setting value is reduced from 3.0m/s to 0.2m/s. When the metal ground return line is converted, the current fluctuation causes the oil flow to change, and the relay malfunctions.

In response to the above two incidents, the State Grid Corporation of China began in 2016 to carry out hidden danger investigation and transformation work on the converter and variable oil flow relays in the entire network. Combined with this work, the current HVDC converter oil flow relay has these main hidden dangers:

4.1. Not regularly inspected as required
In this case, no matter what structure or configuration of the oil flow relay, it is easy to cause the protection to refuse or malfunction.

Take the oil flow relay with double contact structure as an example, its parallel configuration is shown in Figure 8.

![Figure 8. Diagram of double configuration in parallel method.](image)

It can be seen from Figure 8 that any misoperation of any contact or a single component failure in the signal transmission circuit will cause the protection to malfunction.

4.2. Bare metal at the root of the reed switch pin
The hidden danger is currently only found in the products of the German EMB company, which has been confirmed with the German EMB company that all its oil flow relays produced before July 2013 have exposed metal at the root of the reed switch pin and incomplete insulation, as shown in Figure 9.

With the gradual increase of the continuous operation time of the oil flow relay, this hidden danger will greatly increase the possibility of free carbon and impurity accumulation at the root of the reed switch pin, which will cause the root of the reed switch to be short-circuited and cause the oil flow relay to malfunction.

![Figure 9. The EMB design of oil-flow relay around 2013.](image)
4.3. Double contact structure form single contact configuration

With the development of the oil flow relay structure, three contacts have become the mainstream choice in the market. However, the double contact structure is still widely used. In many cases, only one tripping contact is connected to a non-electric protection device. This contact is wrong. The failure of a single component in the signal transmission loop or the signal transmission circuit will cause the protection to malfunction, as shown in Figure 10.

![Figure 10. Diagram of single configuration.](image)

4.4. Three sets of non-electrical protection devices are configured, and the number of contacts of the oil flow relay is insufficient, which can be expanded through the reset relay

The first trip contacts of different relays of each transformer are connected in parallel and then connected to the first set of non-electrical protection devices through cables. The second and third trip contacts are handled in the same way as the first, as shown in Figure 11.

There are two problems with this loop structure:

1. All the trip contacts of the same type of relay are connected in parallel and connected to the non-electrical protection device. After any relay is activated, the location of the faulty relay cannot be determined quickly and accurately, and it needs to be checked one by one;

2. If the trip contacts of different relays in the two non-electrical protection devices fail, it will cause the protection to trip the outlet.

![Figure 11. Diagram of different relay in merge way.](image)

Combining the State Grid Corporation's work on the investigation and transformation of the hidden dangers of the converter and variable oil flow relays on the entire grid and the actual situation, there are...
mainly the following feasible and effective measures for the investigation and transformation of hidden dangers.

4.5. Hidden danger investigation measures
Before removing and opening the oil flow relay, it is recommended to confirm whether the oil flow relay is installed correctly, and then use a strong light flashlight to carefully observe the inside of the relay through the relay observation window and make records and statistics. The main observations are:

(1) The integrity of the reed switch;
(2) Carbon deposit at the root of the lead wire of the reed switch;
(3) Oil leakage at the root of the lead wire of the reed switch.

For oil flow relays with the above problems, it is recommended to replace them immediately.

It is recommended to sort out the number of contacts of the oil flow relay and its configuration method, and clarify the number of contacts of the relay and which configuration method to use in actual operation.

The oil flow relay is inspected according to the power industry standard---"DLT 540 Gas Relay Inspection Regulations".

4.6. Hidden danger modification measure

(1) "Two out of three" configuration of oil flow relay

In accordance with the requirements of the “two out of three” action export logic of the converter transformer gas (oil flow) relays of each converter station started by the State Grid Corporation in 2011, it is recommended that new and conditionally modified substations use three contact gas (oil flow) The relay is exported with " two out of three " logic.

Note: The " two out of three " configurations of the oil flow relay are to use a relay equipped with three contacts. Through the "two out of three " logic judgment, the risk of a power outage caused by the misoperation of the relay is reduced, as shown in Figure 7.

(2) Double contact series configuration

For oil flow relays with double contact structures, it is recommended that the oil flow relays of on-load voltage regulators with serious carbon deposits be configured in series with the double contacts under the condition that the reliability of the double contacts is ensured by the inspection. Improve the reliability of relay action.

(3) Increase the oil filter device and replace the filter element regularly

It is recommended to add an online oil filter or an offline oil filter to filter the insulating oil of the tap changer continuously or regularly, and replace the filter element of the oil filter regularly.

Installation of online oil filter: An online oil filter can be installed at the spare oil filter pipeline of the tap switch or between the oil injection and discharge pipelines, and the power distribution and screen cabinets can be added.

Offline oil filter: Using offline oil filter regularly to filter oil through spare oil filter pipeline or connected between oil injection and discharge pipelines.

As shown in Figures 12-14.

Figure 12. Online filter oil machine.  Figure 13. Offline filter oil machine.
(4) The filter element of the oil filter should be replaced regularly in accordance with the operating specifications.

![Filter Image](image)

**Figure 14. Filter.**

(5) Modification or replacement of oil flow relay

For oil flow relays, which are damaged, oil seepage, or carbon deposits at the root of the lead wire, it is recommended to replace them with spare parts immediately. For oil flow relays with carbon deposits at the root of the lead wire in the reed switch, it is recommended to contact the manufacturer immediately during the warranty period, and disassemble it according to the actual situation outside the warranty period.

5. Conclusions

This paper compares and analyzes the working principles of commonly used oil flow relays in converter transformers, expounds the current application status of oil flow relays and related inspection requirements, based on the analysis of hidden dangers and causes of oil flow relays in practical applications, and combines the investigation and transformation of the hidden dangers of the oil flow relays of the converter transformers of the whole network which The State Grid of China carried out, and proposed a targeted transformation plan for the investigation of the hidden dangers. The feasibility and effectiveness of the scheme were verified by the actual operating conditions on site.

References

[1] Wanjun Zhao 2011 HVDC Engineering Technology (Second Edition) Beijing: China Electric Power Press 18-29
[2] Wenbin Ci, Xiaoming Liu and Yutian Liu 2011 Commutation failure simulations of ±660kV Yindong-Jiaodong HVDC line *Power System Protection and Control* 39(12) 134-139
[3] Yulong Ma 2006 Stability analysis of HVDC transmission system *North China Electric Power University (Beijing)*
[4] National Energy Administration. DLT 540-2013, Gas Relay Inspection Regulations[S]. Beijing: China Electric Power Press, 2014
[5] Baleben Motor and Equipment Manufacturing Co., Ltd. EMB Gas Relay Selection and Operation Instructions[M]. 2001
[6] Yanbing Zhang, Jin Zheng and Dingzhen Nie 2006 Analysis of the problem of electrification of oil flow in large converter transformers[J]. *Power System Technology* 30(23) 6-10
[7] Maotao Liu, Shubo Song, Chao Xie and Zhijie Hao 2010 Analysis and treatment of low-end converter transformer vacuum on-load voltage regulating switch oil flow relay tripping of Yunguang HVDC project[J]. *Southern Power Grid Technology* 4(2) 88-90
[8] Guang Ji and Taoxi Zhu 2010 Discussion on Abnormal Operation of Converter Transformer in Guangzhou Converter Station and Measures[J]. *Relay* 38(1) 115-119+124
[9] Chao Xie, Yong Sun and Zhijie Hao 2010 Analysis of the influence of the radiator in the oil circulation loop on the protection relay of the UHV converter transformer on-load tapping switch[J]. *Transformer* 47(12)