Discussion on Multi-Dimensional Diagnostic Technology Based on Fault of On-load Tap-changer

Bing Yu\textsuperscript{a}, Zhi Yang\textsuperscript{b}, Haofan Lin\textsuperscript{c}, Yongtao Jin\textsuperscript{d} and Yong Yang\textsuperscript{e}

State Grid Zhejiang Electric Power Research Institute Hangzhou, China

E-mail: \textsuperscript{a}1053696370@qq.com; \textsuperscript{b}382241850@qq.com; \textsuperscript{c}449243972@qq.com; \textsuperscript{d}jyt2001@126.com; \textsuperscript{e}382241850@qq.com

Abstract. On-load tap-changer is widely used in current power systems. Its main function is to change the position of the transformer winding tap-connect when operating under transformer excitation or load. The on-load tap-changer is in the process of changing taps. In the middle, the resistor must be used to achieve the transition to limit the circulation during its transition. The structure of the on-load tap-changer can be divided into three parts, namely the switch, the tap selector and the operating mechanism. The complexity of the mechanism causes frequent failures of the on-load tap-changer. Through the analysis of the causes of multiple faults occurring on the on-load tap-changer of the transformer, the abnormal physical information of the on-load tap-changer before the fault occurs is discussed. A joint detection technique based on vibro-acoustic fingerprint and driving motor current (acoustic and electric) is proposed.

1. Introduction

The on-load tap-changing transformer is a very important transmission and distribution equipment in the power system substation [1-4]. It realizes the on-load voltage regulation of the high-voltage transmission and distribution network through the step-by-step operation of the on-load tap changer (OLTC), so that the industrial power supply the system voltage with residential electricity is stable [5]. The on-load tap changer is the only movable part of the on-load tap-changer and one of the key components. Relying on the accurate and timely action of the on-load tap changer can not only reduce and avoid large fluctuations in voltage, but also force distribution of load flow, ensure safe and reliable operation of the power system, and increase flexibility of power grid dispatching [6-7].

There are various failure modes of the on-load tap changer, including the breakage of the drive shaft, the poor contact between the switch contacts, the refusal and slippage caused by the failure of the operating mechanism, the failure of the limit switch, the switch being rejected, the suspension or the action is delayed, the internal fasteners are loose and falling off[8]. Mechanical failure is the main type of fault in the on-load tap changer. It can damage the on-load tap changer and power transformer, affecting the normal safe operation of power equipment and systems and causing serious consequences [9].

In addition to the failure of the internal electrical and mechanical structure of the on-load tap-changer to cause a safety production accident, the on-load tap-changer oil chamber is flooded due to external environmental factors or poor construction process [10].

In recent years, joint detection technology based on vibro-acoustic fingerprints and driving motor current (acoustic electricity) has been widely recognized and practically applied[11]. The main
detection method of OLTC using the combined sound and power detection technology is periodic inspection, including (1) performing on-the-spot detection of each gear position during offline maintenance of OLTC. This method often has a long interval of detection and needs to be planned; (2) The detection cycle interval of the live detection is relatively short, but only the front and rear gears of the current running gear can be detected. The state data of the overall gear position of the OLTC is insufficiently collected and the detection is not comprehensive[12].

Therefore, an online monitoring and analysis device capable of real-time effective monitoring of the on-load tap-changer and capable of automatically analyzing abnormal waveforms is very practical[13]. Establishing and improving the on-load tap-changer fault diagnosis and early warning system not only needs the perfection of the hardware system, but also supplements the abnormal acoustic-electric waveform database corresponding to different faults, realizes the adaptive of fault warning, and improves the accuracy of the pre-judgment.

2. Fault Case

During the annual inspection of a converter station, when the on-load tap-changer is tested for shifting, the human ear hears a frictional click sound inside. In order to clarify the cause of the internal fault, the on-load tap-changer is opened for inspection, as shown in Figure 1.

![Check results of the on-load tap-changer](image)

**Figure 1.** Check results of the on-load tap-changer

Figure 1(a) shows the outer cover of the switch upper cover temperature measurement PT. The sheath has friction with the inner core of the on-load tap-changer during the thermal expansion and contraction due to the installation distance being too small, and the abnormal noise of the mechanism disappears after grinding. Figure 1(b) shows the brown unidentified material appearing in the upper pressure equalizing ring of the core. It is initially suspected to be rust caused by moisture inside the on-load tap-changer.

In order to further ensure that there is no damp situation inside the on-load tap-changer, the converter is loaded with the on-load tap-changer for the core inspection, and the oil sample test is taken directly from the on-load tap-changer body. The on-load tap-changer hoist was placed on the inspection table. It was found that there was a large amount of black unidentified material on the top of the on-load tap-changer and on the surface of the cast iron, as shown in Figure 2 and the black substance could be adsorbed by the magnet.

At the same time, the on-site technicians sampled and tested the sample to determine its exact
chemical composition (two in total, one for the pressure equalization ring and one for the cast iron surface sample). During the sampling process, it was found that there was a suspected water drop at the bottom of the top pressure ring oil, which had a clear boundary with the insulating oil, could not be dissolved in the insulating oil and had a specific gravity greater than that of the oil, and was deposited at the bottom. Because the content was too small, the sampling test could not be performed.

After the sling, a large amount of unidentified liquid and black deposits appeared on the bottom of the on-load tap-changer insulation barrel, as shown in Figure 3(a). The liquid is incompatible with the insulating oil and deposited on the bottom. As shown in Figure 3(b), the field technician samples and sends the liquid and the bottom oil sample, and the sample shows a significant stratification phenomenon after sampling.

After material testing and oil sample micro water testing, the results are as follows, the unknown liquid is water. The specific data is shown in Table 1.
Black unidentified material is rust. The powder samples taken from the cast iron parts were tested after washing with absolute ethanol. The results are shown in Figure 4 and Table 2.

Table 1. Sample water content

| Moisture content | Sample name | Sample 1 | Sample 2 |
|------------------|-------------|----------|----------|
| Water content in oil | 65.5 | 63.5 | 70.2 | 73.7 |
| Average value | 64.5 | | 71.9 |

(a) Electronic mirror imaging  
(b) Composition map

Figure 4. Solid powder composition analysis image

Table 2. Solid powder chemical content table

| Element | Weight percentage | Atomic percentage |
|---------|-------------------|-------------------|
| C K     | 0.29              | 0.71              |
| O K     | 34.68             | 64.59             |
| Fe K    | 65.03             | 34.69             |
| Total amount | 100.00          |                   |

The on-load tap-changer enters the water and causes corrosion. The situation is serious and may cause serious consequences. Therefore, it is possible to predict in advance the abnormality inside the on-load tap-changer, which is convenient for troubleshooting.

3. Principle of Theoretical Detection

3.1 Vibration Acoustic Fingerprint Detection Principle

When the transformer on-load tap changer is in operation, the contact separation between the moving and static contacts will generate a pulse impact force and generate a vibration signal. The vibration signal is transmitted to the terminal through the static contact or transformer oil, and then transmitted
to the transformer tank through the transformer oil. The various vibration signals recorded during the operation of the switch contain a large amount of information about the mechanical aspects of the operation of the on-load tap changer, and each transformer of each brand has its own acoustic fingerprint. Therefore, the condition of the OLTC can be judged by detecting the vibration signal of the OLTC terminal or the surface of the transformer tank online.

When there is a hidden danger in the OLTC, the vibration signal of the surface caused by the action will be different from that in the normal state. Therefore, the waveforms of these action processes can clearly reflect the condition of the OLTC.

3.2 drive motor performance detection principle
The drive motor operating mechanism is a position control and transmission device for changing the operation of the on-load tap changer. It is mounted on the side wall of the transformer tank and is connected to the tap changer by means of a horizontal drive shaft, a bevel gear box and a vertical drive shaft. The power source for the action of other mechanisms of the on-load tap changer.

If the performance of the energy storage spring changes during the switching process of the on-load voltage regulating switch or there is a mechanism jam in the energy storage process, it is inevitably accompanied by a change in the driving torque of the motor, so that the current of the driving motor changes. Therefore, the current sensor can be used to detect the motor drive current to track the change of the performance of the drive motor in real time, so as to effectively judge the operating state of the operating mechanism.

3.3 Transmission shaft rotation characteristics detection principle
The vertical transmission shaft and the horizontal transmission shaft are power transmission parts, and their rotation characteristics reflect the rotation characteristics of the drive motor. The rotation speed reflects the change of the drive current, and by detecting the rotation direction of the transmission shaft, the shift state of the OLTC can be judged. And compared to the drive motor, the vertical drive shaft and the horizontal drive shaft are outside the housing for easy measurement.

When the drive current of the drive motor changes, the resulting speed change phenomenon is transmitted to the drive shaft. Due to the mechanical transfer characteristics, the speed change caused by the rotary shaft is completely consistent with the characteristics of the drive motor.

4. Expected Goal
The above three detection principles aim to realize fault self-identification early warning, and the premise of successfully implementing fault type judgment is the construction of fault database. The massive fault data is integrated into the expert database, and the artificial fault can be realized by the special person periodically performing the typical fault case input update.

The initial application of the on-load tap-changer fault intelligent identification and early warning technology will inevitably lead to misjudgment, requiring timely intervention by the operation and maintenance personnel. With the long running time and the accumulation of cases, the characteristic features of the fault signature waveform are clear, and the fault diagnosis based on artificial intelligence It is also more accurate, and finally the function of fault diagnosis and identification of the fully automatic all-weather on-load tap-changer can be realized.

Reference
[1] Faiz, J, Siahkolah, B. New Solid-State on-Load Tap-Changer Topology for Distribution Transformers[J]. IEEE Power Engineering Review, 22(8):71-71.
[2] Arrillaga, J, Duke, R.M. A Static Alternative to the Transformer On-Load Tap-Changer[J]. IEEE Transactions on Power Apparatus & Systems, PAS-99(1):86-91.
[3] Y.-Y. Wang, J.-J. Zhou, J. Li, et al. An assessment method for the reliability of on-load tap-changer of power transformer[J]. Journal of Chongqing University, 2010.
[4] TOJO,Shinichi. Loading Guide for Individual Transformers with On-load Tap-Changer Facility
and the Comparison of Calculation Results with Established Loading Guide and the Consideration[J]. Ieej Transactions on Power & Energy, 2004, 124(9):1161-1168.

[5] Liu X, Jinzhong L I, Gao F, et al. Key Technology Research for Vacuum Type On-load Tap-Changer of ±800kV Direct Current Convertor Transformers[J]. 2016 (19).

[6] Yan, Ruifeng, Marais, Brandon, Saha, Tapan Kumar. Impacts of residential photovoltaic power fluctuation on on-load tap changer operation and a solution using DSTATCOM[J]. Electric Power Systems Research, 111:185-193.

[7] Cichon A, Borucki S, Boczar T, et al. The possibilities of using acoustic signals generated by the on load tap changer[C]// 2012.

[8] Kang, P, Birtwhistle, D. Condition monitoring of power transformer on-load tap-changers. I. Automatic condition diagnostics[J]. IEE Proceedings-Generation, Transmission and Distribution, 148(4):301-0.

[9] Antonio Z, Junjie H, Massimiliano C, et al. Experimental testing and model validation of a decoupled-phase on-load tap-changer transformer in an active network[J]. 2016, 10(15):3834-3843.

[10] Jiang Fan, Z. Bo. Modelling of on-load tap-changer transformer with variable impedance and its applications[C]// Energy Management and Power Delivery, 1998. Proceedings of EMPD ’98. 1998 International Conference on. 1998.

[11] Duan, Ruochen, Wang, Fenghua. Fault Diagnosis of On-Load Tap-Changer in Converter Transformer Based on Time-frequency Vibration Analysis[J]. IEEE Transactions on Industrial Electronics:1-1.

[12] Nan C, Jonsson L. E. A new Hybrid power electronics on-load tap changer for power transformer[C]// 2015.

[13] R. Duan, F. Wang, L. Zhou, et al. Mechanical Condition Detection of On-Load Tap-Changer in Converter Transformer Based on Narrowband Noise Assisted Multivariate Empirical Mode Decomposition Algorithm[J]. Transactions of China Electrotechnical Society, 2017, 32(10):182-189.