Monitoring and Influencing Factors Analysis of Nitrogen Pressure during Storage and Transportation of Large Transformers

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Abstract. During the storage and transportation of large power transformers, nitrogen filling is needed to prevent moisture inside the oil tank. The traditional nitrogen pressure monitoring method is to install mechanical pressure gauges on the oil tank. The supervisor will check the nitrogen pressure and supplement it manually. This way can't achieve the remote monitoring and the real-time alarm of nitrogen leakage. By means of a remote on-line monitoring system for transformer storage and transportation, the process real-time status data could be collected and analyzed. The relationship between the nitrogen pressure, environment temperature, altitude and the impact acceleration of will provide guidance for the power transformer storage and transportation planning or management.

1. Preface

Most of large power transformers adopt fully sealed oil-immersed structure. To reduce the influence of oxygen and moisture on the internal insulation of transformers, the solid insulation parts will undertake strict vacuum drying and oil immersion procedures before leaving factory. Considering the weight, the transformer oil and transformer body are usually transported separately. Meanwhile, the nitrogen filling transportation is used to avoid the oxygen and moisture entering into the transformer tank.

In the relevant standards such as "GB/T 6451 Specification and technical requirements for the three phase oil immersed power transformers" and "GB 50148 Code for construction and acceptance of power transformers oil reactor and mutual inductor", nitrogen-filling and monitoring in the transportation of power transformers are definitely required. The transformer or reactor storage and transportation should be inflated with enough nitrogen or drying air which could keep the tank with positive pressure between 0.01 to 0.03Mpa.

Usually, the end users or transformer factories will check manually the pressure gauge for the internal pressure monitoring of the transformer on the freight yard or in transit. This kind of management could not realize the real-time monitoring or avoid the personal operation mistakes.

Based on years of transformer storage and transportation experience, this paper studies the nitrogen pressure monitoring equipment with integrated nitrogen pressure, temperature monitoring and remote communication function. Through the application of this equipment, the real-time and online monitoring
of storage and transportation of power transformers could reduce the labor cost and personal mistake. At the same time, the corresponding relationship between nitrogen pressure inside transformers and external environmental factors such as temperature or altitude could be studied through the measured data which could also give guidance for the Nitrogen filling and transportation scheme.

2. Current situation and problems in transformer nitrogen filling and transportation

In order to avoid dampness of transformer in the process of storage or transportation, transformer is required to inflate nitrogen and maintain a positive pressure from 0.01 to 0.03Mpa between the inside and outside of tank. However, in the actual circumstances, there are still nitrogen pressure leakage caused by following two main reasons:

2.1. Defects of manual monitoring mode

The existing nitrogen pressure monitoring method in the process of transformer storage and transportation is to check the mechanical gas pressure gauge which is installed on the transformer body. The monitoring data is recorded periodically by manual, but the polling interval frequency is low. It is usually read once a day in the process of transportation, and not more than once a day during the storage at the freight yard. Because of the slow response, it is difficult to deal with the damp problem in time when an accident leakage occurs.

2.2. Nitrogen pressure exceed seal component limit

Due to the characters of long distance and long time transportation of power transformer, the pressure difference between inside and outside of transformers will change according to influence of the ambient temperature, geographical altitude, transportation impact and so on. If the pressure difference exceed limit, the seal component will be damaged and leakage will happen.

3. Influence factors of the nitrogen pressure changing

Through analyzing the online monitoring data which is measured and sent by the intelligent pressure sensor and monitor installed on the transformer tank like Figure 1, the influence factors of the nitrogen pressure inside transformer could be studied.

![Figure 1. Pressure sensor and monitor installation](image)
3.1. Analysis of pressure changing during storage period

When the transformers are manufactured completely, it may be temporarily stored for a period of time before they left the factory or after they arrived on site. In this process, nitrogen or drying air is required to fill the transformer to prevent dampness.

The following Figure 2 shows one actual online nitrogen pressure measuring data of a stored transformer:

![Figure 2. Pressure measuring curve of one transformer in storage period](image)

The curve in Figure 2 shows the 10 day nitrogen pressure changing of one transformer stored temporarily at Jiuquan city of the Gansu province. From the data, it can be seen that the internal pressure of the transformer varies between 0.04 and 0.05 Mpa, and the change trend changes periodically on a daily basis.

It is preliminarily analyzed that the change of nitrogen pressure in the transformer may be caused by the change of ambient temperature. The nitrogen pressure values of one day could be compared with the environmental temperature data in Table 1:

| Time (Clock) | Pressure (Mpa) | Temperature (℃) |
|--------------|----------------|-----------------|
| 0            | 0.0462         | 7               |
| 2            | 0.0458         | 6               |
| 4            | 0.0456         | 4               |
| 6            | 0.0454         | 3               |
| 8 (Sunrise)  | 0.0450         | 2               |
| 10           | 0.0442         | 8               |
| 12           | 0.0448         | 13              |
| 14           | 0.0454         | 16              |
| 16           | 0.0460         | 16              |
| 18 (Sunset)  | 0.0470         | 15              |
| 20           | 0.0470         | 11              |
| 22           | 0.0462         | 8               |
Figure 3. Curve of relationship between nitrogen pressure and environmental temperature

From the above Figure.3, some result could be ensured:

- The internal nitrogen pressure of the stored transformer changes basically in the same trend with the ambient temperature.
- Because the time of heat conduction, the change of nitrogen pressure delay a little after the change of ambient temperature.
- The maximum temperature difference in a day is 14°C, and the maximum pressure difference in a day is 0.0028Mpa. It can be concluded that every change in temperature of 1°C will bring about 0.0002Mpa change of nitrogen pressure.

In summary, the change of nitrogen pressure inside the transformer during storage is mainly affected by the ambient temperature, and the change rate of nitrogen pressure per centigrade ambient temperature is about 0.5%.

3.2. Analysis of pressure changing during transportation period

The intelligent pressure sensor and monitor installed on the transformer tank could measure not only the nitrogen pressure but also the transportation speed, impact acceleration and GPS position in the process of transformer transportation.

Figure 4. Three axis impact acceleration curve (above), nitrogen pressure curve (below)
From the above Figure 4, it can be seen that the nitrogen pressure fluctuation during the transformer movement more than the static state of the transformer (the three-axis impact acceleration is 0) due to the influence of movement and impact.

The five typical values of nitrogen pressure variation and three axis impact acceleration values are compared as following Table 2:

**Table 2. Nitrogen pressure and three axis impact acceleration comparison**

| No | Pressure (Mpa) | Impact acceletation (g) | X axis | Y axis | Z axis |
|----|----------------|------------------------|--------|--------|--------|
| 1  | 0.0532 (peak) | 0.8                    | -0.1   | -0.5   |        |
| 2  | 0.0504 (peak) | 0.4                    | -0.2   |        | 0.7    |
| 3  | 0.0476 (peak) | 0.7                    | 0.2    |        | 0.5    |
| 4  | 0.0400 (valley)| 1.5                    | -0.3   |        | 0.8    |
| 5  | 0.0442 (peak) | 1.2                    | -0.1   |        | -0.5   |

From the Table 2, it can be seen that when the nitrogen pressure inside the transformer changes more, the three-axis impact acceleration of the transformer at the same time is also bigger. The impact vibration of the X-axis is caused by the change of the transportation speed, and the impact vibration of the Z-axis is caused by the transportation bump.

Therefore, the change of speed and turbulence in the process of transformer transportation will not only cause the change of impact acceleration, but also cause the change of nitrogen pressure in the transformer. Ensuring smooth and stable transportation process can also ensure the nitrogen pressure inside the transformer is stable and reduce the risk of leakage.

3.3. Analysis of pressure changing at different geographical position

The transportation of large transformers is usually long distance transportation, and the altitude at different locations is also different. Different altitudes cause the change in atmospheric pressure. The corresponding relationship between altitudes and atmospheric pressure is about 0.67Kpa per 100m altitude change.

Taking this actual transportation as an example, the transport starts at the altitude of 800 meters and the transport destination at the altitude of 50 meters. The external atmospheric pressure of the transformer caused by altitude changes increases by 0.67*7.5=5.025Kpa. The ambient temperature at the start of transportation is 31°C, and the ambient temperature at destination is 13°C. The temperature difference is 18°C, and the 3.2 section of the analysis temperature changes every 1°C will bring the change of 0.2Kpa nitrogen pressure.

Considering the factors of altitude and ambient temperature together, the theoretical calculation of the difference of nitrogen pressure measured between the origin and destination is 5.025+3.6Kpa = 8.625Kpa = 0.0086Mpa without leakage of nitrogen pressure in the transformer. The actual difference of nitrogen pressure between the origin and destination is 0.0386-0.0288 = 0.0098Mpa, which is close to calculation value.

4. Conclusion

By means of a remote online monitoring system which could measure real-time data and communicate with remote control center, the author monitors and records the status data of transformer during storage and transportation. It provides a method for monitoring and risk control of nitrogen pressure in transformers. Through the analysis of the transformer storage and transportation monitoring data, it is concluded that the transformer nitrogen pressure changes correspond to the environment temperature, impact acceleration and other position changes in the transport process as follows:

1. The ambient temperature can affect the nitrogen pressure in the transformer during the storage or transportation. The change of temperature is 1°C and the change of nitrogen pressure is 0.2Kpa.
2. The impact acceleration of the transformer in the transportation process will also affect the nitrogen pressure in the transformer, so controlling the impact acceleration of the transformer in the transportation process will also reduce the risk of transformer nitrogen leakage.

3. Altitude change of transformer long-distance transportation also affects the nitrogen pressure change inside transformer. Every change of altitude 100 meters will bring the change of nitrogen pressure 0.67Kpa.

In summary, through the study of this paper, it can be concluded that the nitrogen pressure in the transformer storage and transportation process is affected by the transformer three-axis impact acceleration, environmental temperature and altitude changes. These factors should be fully taken into account in the process of transformer transportation planning, and if it is possible, nitrogen automatic replenishment and release devices and the online monitoring system should be equipped to reduce the leakage chance.

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