Research on On-line Monitoring and Regulation Technology of Pressure of High Voltage Transformer

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Abstract. In order to analyze the operating status of voltage and current transformers at high voltage levels, the methods of detecting transformer insulation level and infrared temperature are usually used, but such methods usually use manual measurement by portable instruments, and the internal defects of the transformer are difficult to find in time. This article proposes a suitable on-line monitoring method and regulation technology for the insulation oil pressure of high voltage transformers. The defects of the transformer can be judged by the change of the internal oil pressure, which can effectively find faults such as internal short-circuit, degradation, and partial discharge of the transformer. A mechanism is designed to adjust and release the pressure of expanders. The high voltage transformer pressure line monitoring device has developed based on the Internet of Things communication and solar power supply mode, which can monitor the internal operating status of the transformer in real time. When the internal pressure of the transformer suddenly increases, the designed pressure release structure of the expander will automatically rupture, release the internal pressure of the transformer, ensure the safety of the transformer body, and reduce the impact of the accident.

1. Introduction

With the development of China's electric power industry, the reliability requirements for the operation of transmission and transformation equipment have become higher and higher. Voltage and current transformers are one of the important power equipment in substations. Their safe operation affects the safety and reliability of the power grid directly. Therefore, it is necessary to monitor the operating status of voltage and current transformers. At present, national standards stipulate that the internal pressure adjustment of the transformer is achieved by installing an expander. However, the expandability of the expander has certain limitations. At present, most of the detection methods of the transformer during normal operation are portable, charged instruments, such as collecting samples of the oil medium inside the transformer, analyzing the gas content in the oil, the dielectric loss of the bushing and the external infrared temperature measurement [1]. However, the above methods cannot measure the internal faults of the transformer in real time and accurately. It can only indirectly reflect the problem from other parameters after the internal faults have formed for a period of time [1-2]. This article proposes a wireless communication method based on solar power. On the expander installed on the top of the transformer, the internal pressure change of the transformer is monitored online, and an
alarm is actively sent when the internal pressure of the transformer reaches a certain pressure value. A self-explosive pressure release device for the transformer is designed to protect the transformer body's operation safety by releasing the pressure on the expander when the internal pressure of the transformer reaches the limit value.

2. Transformer internal pressure measurement method and principle analysis

2.1 Transformer internal pressure measurement method and principle

When the transformer is in operation, its internal pressure is:

\[ P = P' + \Delta P \]  

Above \( P' \) —— changes in internal pressure due to changes in ambient temperature and normal heating during transformer operation, designed pressure at \( T = 20^\circ C \)

\( \Delta P \) —— the increment of pressure due to internal failure

Under normal state, its pressure \( P = P' \), \( \Delta P \) is related to many factors, it is a function of discharge \( Q \) and short-circuit current \( I \), that is, \( \Delta P = f(Q, I) \). Under normal state, \( \Delta P = 0 \).

When the transformer's insulating medium fails, it appears as an increase in discharge and an increase in active loss. The capacity of this part will crack the transformer oil and increase the gas production rate, as shown in figure 1.

Figure 1. The change curve of transformer internal insulation fault pressure

The point \( N \) is called the inflection point, which is the critical point. Before the point \( N \) is normal state, and passed the point \( N \) is failure state. After the internal pressure of the transformer increases due to a fault, the energy of this part is transferred to the expander to deform it. With the development of the fault, the gas production rate further increases and the expander deforms more severely. This is a dynamic process. When the dielectric strength of the insulating medium has completely disappeared, a large short-circuit current flows through the internal insulation of the transformer, and a transient shock pressure wave is generated. Its strength outdistances the damage degree of the porcelain sleeve. At this time, if the expander can absorb the released energy in a short time, it can prevent the failure. However, it generally takes about 60 to 100 ms from the breakdown of the insulating medium to the explosion. Changing from one state to another will inevitably change the pressure. The pressure change is completely reacted on the expander. All pressure sensors can be designed on the expander to monitor the pressure change in real time.[3-5]

Firstly, the piezoresistive pressure sensor is formed by using the piezoresistive effect of single crystal silicon. A single crystal silicon wafer is used as an elastic element, and an integrated circuit process is used on the single crystal silicon diaphragm to diffuse a set of equivalent resistors in a specific direction of the single crystal silicon and connect the resistors into a bridge circuit. The single crystal silicon wafer is placed in the cavity of the sensor. On the sealing plate of the expander, a thread seat of an oil sealing device matching the sensor is welded, and the pressure sensor is connected to the expander through a screw thread. When the pressure changes, the single crystal silicon generates strain. The strain resistance which diffuses directly on it is changed proportional to the measured pressure, and then the corresponding voltage output signal is obtained by the bridge circuit. The piezoresistive pressure sensor is used in the study. The resistance strain effect is to change the resistance value of the strain gauge through mechanical deformation to achieve the purpose of converting the pressure signal into an electrical signal. The pressure monitoring range of the 66kV transformer is 0-0.15Mpa. In the meantime, the measurement results are transmitted to the data terminal by wireless transmission.
3. The regulation of transformer pressure and the design of pressure release

The transformer pressure regulating device is installed on the expander, which includes a housing composed of an upper cover, a bottom plate and an outer cover with an oil level observation window and the corrugated expansion unit are assembled in the housing with the oil injection valve, pressure release device and oil level indicating mechanism. The technical points are as follows: the central oil inlet of the lower sealing plate of the corrugated expansion unit is sealed through a connecting seat with the oil inlet of the bottom plate of the housing; the bottom plate is fixed on the porcelain sleeve flange by a sealing rubber ring, and the internal insulating oil of the porcelain sleeve communicates with the central oil inlet hole of the lower sealing plate of the corrugated expansion unit; the pressure release device consists of a pressure release membrane and a pressure release needle, and is fixed by a pressure release membrane made of a center-stressed and fragile load-bearing profile in the connection hole on the side of the oil filling valve of the sealing plate on the corrugated expansion unit, the pressure release needle is fixed inside the upper cover of the housing. When the corrugated expansion unit is in the free state, the distance between the upper surface of the pressure release membrane and the needle tip is not exceeding the rated expansion height, the locating pin above the ring-shaped stiffener on the upper end of the casing is matched with the locating slot of the casing upper cover, so that the center of the pressure release membrane and the center of the pressure release needle are on the same center line. When an accident occurs inside the transformer, the pressure release device is triggered. The pressure release needle can quickly pierce the pressure-relief membrane in the center and immediately release the internal pressure of the transformer, insulation oil flows out. As shown in figure 2, to protect the porcelain sleeve from explosion just needs to replace the expander and oil, and then it can run normally.

Figure 2. The internal structure of expander pressure release

4. The whole design of the device

4.1 Overall design

Based on the method of on-line monitoring of the pressure of the high-voltage transformer proposed in this paper, a data communication system based on wireless sensor network and LoRa-WAN Internet of Things was developed. It is powered by solar energy. The solar panel is placed on the upper part of the transformer cover and is introduced into the device by the power supply cable. The pressure sensor of the device adopts a piezoresistive pressure sensor, and chooses a material that can resist corrosion and can be placed in an oil medium for a long time. The pressure signal is converted into a voltage signal through a signal conversion module, and is amplified by the amplifier signal and then enter the MCU. The pressure measurement result is obtained after 10 times of sampling and averaging. The system clock timestamps the currently monitored data and provides it to the background. The memory section can store 1 year of data locally. The LoRa wireless communication circuit is designed to wirelessly transmit the current measurement results to the background through the active upload mode. The overall design block diagram is shown in figure 3.
4.2 Design of pressure measurement circuit

A pressure sensor is installed on the upper part of the expander. After the resistance change of the sensor is converted into a voltage signal, it is converted into a voltage signal with a peak value between $0V \sim +2.4V$. C39 is used as a high-frequency filter capacitor. After filtering out higher harmonics. It enters the second-stage amplifier, after being proportionally amplified, the signal finally enters the internal A/D in the MCU for analysis and calculation to obtain the average pressure, as shown in figure 4.

4.3 Wireless transmission design

This article designs a communication system based on LoRa wireless networking, which can be networked with various measuring points with LoRa communication functions in a substation to achieve edge computing and local data processing. The pressure online monitoring device is on the top of the transformer. All antennas are placed in the window to facilitate data transmission from the transformer because of the window on the outer cover. The wireless module selects E22-400S model and 433MHZ transmission frequency, which can support automatic sleep and wake-up in the air to achieve low power consumption of the entire device. Among them, wireless_rx and wireless_tx are connected to the MCU, respectively, and communicate with each other through the UART function. M1 and M0 are function control pins, and select four working modes: normal, wake-up, power saving, and sleep. This design adopts the methods of automatic sleep and wake in the air, and acquires data from the measurement points periodically. The control circuit is as shown in figure 5.
The solar power supply circuit is designed to provide reliable power to the on-line monitoring device. The solar panel is 3W, the maximum output voltage is 4.5V, monocrystalline silicon is installed on the top cover of the transformer and it is introduced into the power supply circuit of the device through the cable, as shown in figure 6. The energy storage part chooses 3.3V/6AH lithium iron phosphate battery, which has good charge and discharge performance and more stable advantages. TP5000 is a high-performance charging chip that can charge lithium iron phosphate batteries with a maximum charging current of 1.5A and an output of 3.6A. The left part of the picture is the input of the solar panel. Through the TVS and fuse to protect the safety of the circuit operating, the configuration and design of the chip's peripheral circuits can be used to charge lithium iron phosphate battery when the solar panel receives 30% of the irradiation range.

**Figure 6. Solar charging circuit**

5. Conclusion

This article designs an on-line monitoring method for the internal pressure of the high-voltage transformer. By installing a pressure sensor on the expander, the internal fault of the transformer is detected through the change in pressure, which solves the problem that the traditional electrical detection method cannot measure the internal pressure. In addition, a mechanism which can regulate and release pressure is designed in this article. When the internal pressure of the transformer suddenly increases, the internal energy is quickly released to ensure the safety of the body. On-line monitoring the pressure of the high-voltage transformer device uses solar power and LoRa-WAN wireless communication methods to achieve remote transmission of communication networking and data. It can be used to interact with monitor equipment in other stations by this way and realize the interconnection of equipment status information and edge calculation at the bottom of the substation.
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