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TRANSFORMER PROTECTION AND FIRE FIGHTING SYSTEMS USED IN HIGH VOLTAGE POWER STATIONS

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ABSTRACT: This paper presents protection devices and digital protection functions used to protect high voltage power transformers from internal or external faults and abnormal operating conditions. It also presents how a modern firefighting system works in comparison with an older, basic one.

Keywords: power transformer, fault, protection, relay, fire-fighting system

1. INTRODUCTION

Power transformers (Figure 1) are a critical and expensive component of the power system. Due to the long period required for repair or replacement of transformers, a major goal of the transformer protection is limiting the damage to a faulted transformer.

Transformers are protected primarily against faults and overloads. The type of protection used should minimize the time of disconnection for faults within the transformer and to reduce the risk of catastrophic failure to simplify eventual repair. Any extended operation of the transformer under abnormal condition such as faults or overloads compromises the life of the transformer.



Figure 1. Power transformer in high voltage power station

2. TRANSFORMER FAULTS AND PROTECTION DEVICES AND FUNCTIONS USED

Faults in transformers can be classified into [1]:

- ≡ internal faults such as winding failures due to short circuits (phase – phase, phase – earth), core short circuits due to bad insulation, bushing and tap changer failures.
- ≡ external faults and abnormal operating conditions such as overloads, overvoltage, external short circuits.

To protect the transformer from internal faults, high voltage power transformers are equipped with technological protections (Buchholz relay and pressure relief devices) and differential protections (usually one differential protection in each protection group).

2.1. The Buchholz relay [2]

The Buchholz relay (gas detector relay) is placed in the piping between the transformer main tank and the oil conservator. The Buchholz relay construction is presented in Figure 2.

Under normal conditions, the Buchholz relay is full with oil. It consists of two mercury switches attached to a float and a flap valve. The float closes the alarm circuit when oil level drops due to gas accumulation, while the lower flap valve closes the trip circuit in case of serious internal faults.

When gas gets accumulated in the upper part of the Buchholz relay and the oil level drops, the float closes the contacts of the mercury switch attached to it. This completes the alarm circuit and signals it in the substation control room where the operator will know that there is some incipient fault in the transformer.

The transformer is then disconnected and the gas sample is tested in order to find out what type of fault has started developing in the transformer. A very good setting of the mercury switch is required in order for it not to be too sensitive otherwise, the relay can operate due to bubbles, vibration, earthquakes and mechanical shocks.

When a serious internal fault occurs in the transformer, a considerable amount of gas gets generated. The pressure in the transformer tank increases and thus the oil rushes towards the conservator through the Buchholz relay hitting the flap valve. The flap valve closes the mercury switch contacts and completes the trip circuit, which opens the circuit breaker separating the transformer from the network.

A general protection relay does not indicate the appearance of any type of fault. It only operates when fault occurs. The Buchholz relay has a big advantage because it gives an indication of the fault at its early stage due to the gas accumulation and operates the alarm circuit. The gas in oil level can be monitored on the Buchholz relay (Figure 3).

When protecting a high voltage power transformer, two Buchholz relays are being used: one to protect the transformer tank and one to protect the tap changer chamber.

2.2. The pressure relief devices [2]

The pressure relief devices detect a sudden increase of pressure inside the transformer. As well as the Buchholz relay, pressure relief devices are provided for both the transformer tank and the tap changer chamber. As a pressure relief device is recommended for each 25 tons of oil, the tap changer chamber usually has only one, whereas the transformer tank has more than two.

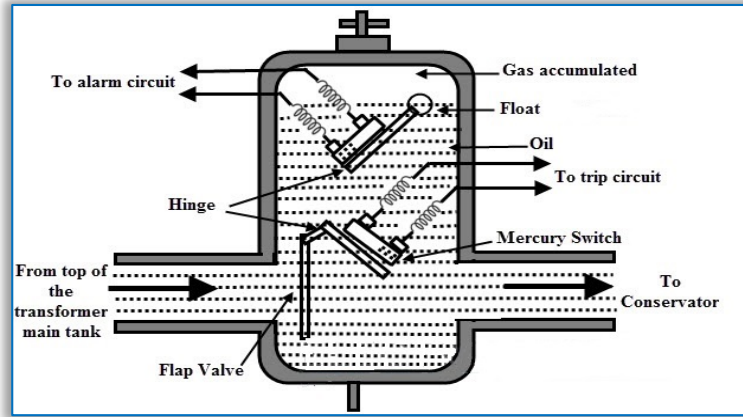


Figure 2. Buchholz relay construction

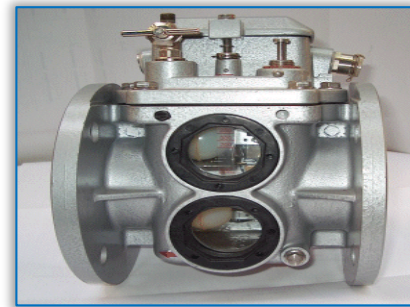


Figure 3. The Buchholz relay

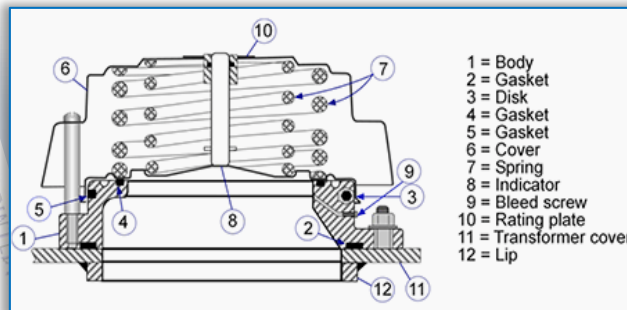


Figure 4. Pressure relief device

The most common form of pressure relief device is the frangible disk type (Figure 4). The surge of oil caused by a heavy internal fault bursts the disk and allows the oil to discharge rapidly. Limiting the pressure rise prevent explosive rupture of the tank and fire. Recently, all pressure relief devices are mounted with pipes to direct the surge of oil to the base of the transformer.

The pressure relief devices are usually fitted with two sets of contacts for tripping: one for the protection group one trip and the second for the protection group two.

2.3. The differential protection [3]

The differential protection is based on current comparison. In normal operation, a transformer is transited by a current I that enters through one side and exits at the other side. If we have two current transformers (CT1 and CT2) mounted on both sides of the transformer (Figure 5), the secondary currents of the current transformers can be connected to form a closed electric circuit with secondary current i .

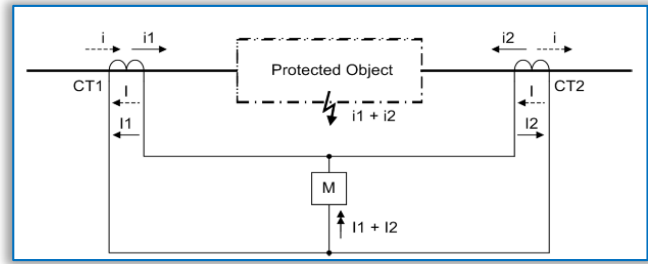


Figure 5. Basic principle of differential protection

The differential protection measuring element M , which is connected to the electrical balance point, measures a zero current in normal operation. When a fault occurs in the area between the two current transformers, the measuring element is fed with a secondary $i_1 + i_2$ current that will make

the differential protection trip due to a fault inside the protected zone.

The following two currents are calculated by the measuring element:

- a tripping or differential current

$$I_{diff} = \left| \underline{I}_1 + \underline{I}_2 \right| \tag{1}$$

- a stabilization or restraining current

$$I_{stab} = \left| \underline{I}_1 \right| + \left| \underline{I}_2 \right| \tag{2}$$

In normal conditions or external faults, the current enter through one side and exits on the other side of the protected zone, therefore:

$$I_{diff} = \left| \underline{I}_1 + \underline{I}_2 \right| = \left| \underline{I}_1 - \underline{I}_1 \right| = 0 \tag{3}$$

$$I_{stab} = \left| \underline{I}_1 \right| + \left| \underline{I}_2 \right| = \left| \underline{I}_1 \right| + \left| \underline{I}_1 \right| = 2 \left| \underline{I}_1 \right| \tag{4}$$

When a fault appears inside the protected zone, the current will enter through each side of the protected zone and presuming that the two currents are equal, the measuring element of the differential protection will calculate:

$$I_{diff} = \left| \underline{I}_1 + \underline{I}_2 \right| = \left| \underline{I}_1 + \underline{I}_1 \right| = 2 \left| \underline{I}_1 \right| \tag{5}$$

$$I_{stab} = \left| \underline{I}_1 \right| + \left| \underline{I}_2 \right| = \left| \underline{I}_1 \right| + \left| \underline{I}_1 \right| = 2 \left| \underline{I}_1 \right| \tag{6}$$

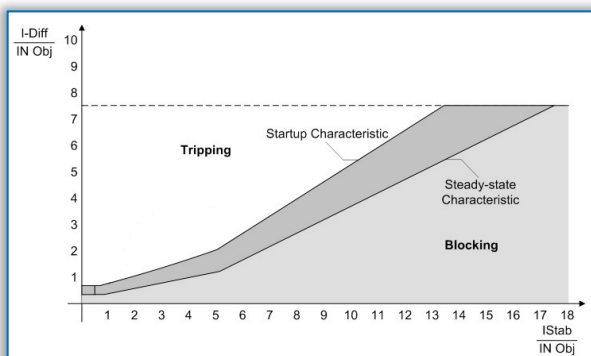


Figure 6. Tripping characteristic of the differential protection

Therefore, in case of a fault inside the protected zone, the differential protection will issue a trip command to the circuit breaker on both voltage levels because the current is within the tripping zone of the trip characteristic (Figure 6).

To protect the transformer from external faults and abnormal operating conditions, high voltage power transformers are equipped with technological protections (oil and winding temperature indicators) and overvoltage and thermal overload protections (usually integrated in the differential protection device).

2.4. Overvoltage and overload protection

The overvoltage protection is needed to protect the transformer from insulating problems caused by abnormally high voltage levels, which can appear due to incorrect manual operation of the generators excitation system, faulty operation of the automatic voltage regulator, prolonged weak loads on overhead lines etc.

The overvoltage protection has two stages. In case of high overvoltage, the trip command is issued with short-time delay, whereas in case of lower overvoltage, the trip command is issued with a longer time delay. The voltage limit values and delay times can be set individually for both stages.

The thermal overload protection prevents damage to the transformer caused by thermal overheating. The protection function takes into consideration the current value that transits the transformer over a period and a thermal replica of the transformer. Both overvoltage and thermal overload protections can be blocked or switched off via a binary input signal in the protection device.

2.5. Oil and winding temperature indicators [4]

The oil temperature indicator (OTI, Figure 7) and winding temperature indicator (WTI, Figure 8) have two essential roles in protecting the transformer. The first one is to measure and display the oil and temperature of the transformer and the second one is to issue the trip command to the circuit breakers on both sides of the transformer in case the temperature value exceeds a settable value.

These indicators can be equipped with contacts that close at different temperature values. Usually they are equipped with three sets of contacts: one for signaling the temperature increase and two for issuing the trip command to the circuit breaker via the numerical protection devices (one contact sends the trip signal to protection group 1 and the other contacts sends it to protection group 2).

3. THE NEED FOR MODERN FIREFIGHTING SYSTEMS [5]

The need for use of transformer firefighting systems has been discussed for many years and varieties of practices have evolved. Some transformers have been constructed and are in use with firefighting systems while others have no fire suppression systems installed.

Transformer fires are rare but the impact they have is huge. Even though a transformer involved in a fire will likely be destroyed almost immediately, the fire’s effect on adjacent equipment and structures can be contained and therefore must be considered. An uncontained fire can do a significant amount of damage and result in a prolonged, unscheduled outage (Figure 9).

Many of the transformers in use are equipped with water firefighting systems (Figure 10) intended to extinguish a transformer fire. Conventional firefighting systems have proven to combat transformer fires effectively but they consume large quantities of water and therefore require a complex dimensioning of the firefighting system. Additionally, the discharged water can be contaminated with transformer oil and will need to be collected for later processing. To this end, the floor pan must be dimensioned to ensure that it can collect not only the oil, but also the water.

A disadvantage of the traditional water fire fighting system is that it is started by one of the following two conditions: a Buchholz relay trip or a differential protection trip. There have been cases when

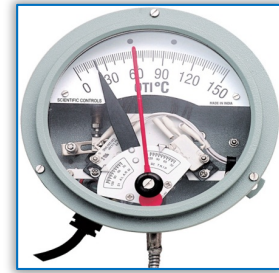


Figure 7. Oil temperature indicator (OTI)



Figure 8. Winding temperature indicator (WTI)



Figure 9. Results of an uncontained transformer fire



Figure 10. Transformer equipped with firefighting system

a Buchholz relay issued the trip command without a real fault inside of the transformer due to ageing and sealing problems. Water got inside of the Buchholz relay thus its contacts “got closed” and the transformer tripped.

4. THE MODERN SERGI FIREFIGHTING SYSTEM [6]

The modern Sergi firefighting system uses a nitrogen injection system. This system is designed to prevent tank explosion and fire during internal faults, and extinguish the external oil fires on transformer top due to tank explosion, bushing fires etc. The system shall drain a quantity of oil from the tank top to reduce the tank pressure and inject high-pressure nitrogen gas to the lower side of the tank to reduce the oil temperature at the top of the tank in order to extinguish the fire. There are two types of nitrogen injection systems:

- One that protects the transformer tank and tap changer compartment, type TPA presented in Figure 11;
- One that also protects the transformer bushings additionally to the previous two, type TPAB presented in Figure 12.

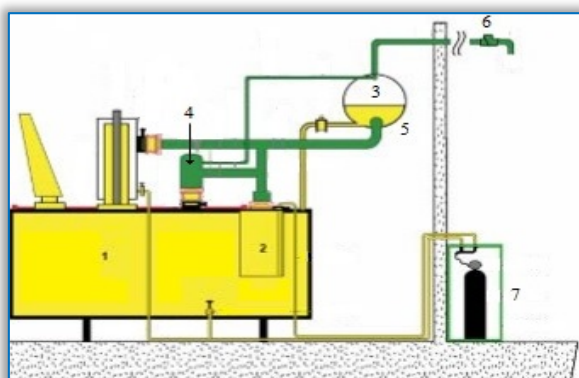


Figure 11. Nitrogen injection system type a

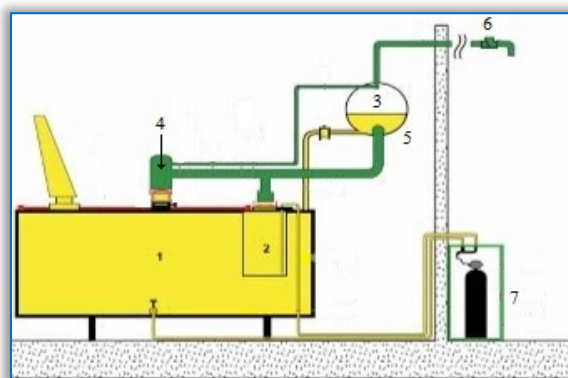


Figure 12. Nitrogen injection system type b

Both nitrogen injection systems include the following: 1 – Transformer tank; 2 – Tap changer compartment, 3 – Transformer conservator; 4 – Decompression chamber; 5 – Oil / gas separation compartment included in the transformer conservator; 6 – One way direction air valve, 7 – Nitrogen tank.

The decompression chamber can be built vertically, horizontally or at a 45 degree angle (Figure 13). It contains a rubber disk (Figure 14) that will rupture when pressure level hits a predefined value and release the excess pressure to the oil / gas separation compartment. The rubber disk will rupture with a time delay of 0.5 to several ms depending on the pressure.



Figure 13. Constructive types of the decompression chamber



Figure 14. The rubber disk inside the decompression chamber

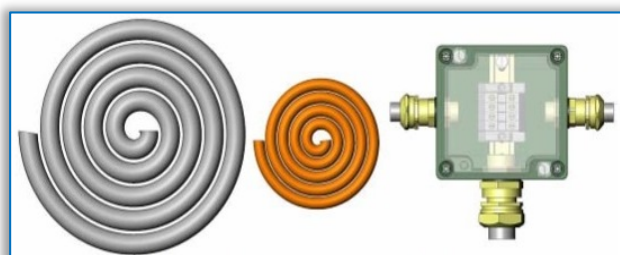


Figure 15. The linear heat detector

The nitrogen system also includes a linear heat detector (LHD presented in Figure 15) which is mounted on the top of the transformer. It consists of two metallic wires separated with polymeric insulation. When at the transformer top the temperature reaches 138 degrees Celsius, the polymeric insulation melts and the two metallic wires touch, thus sending a linear heat detection signal to the firefighting system.

The nitrogen injection system can work in manual or automatic mode. In manual mode, to start the nitrogen injection, it is required that a working staff member to press the manual injection button. In automatic mode, the system has three operation modes:

- a. Prevention mode: To active the prevention mode, the system needs to receive a rubber disk rupture signal + Buchholz relay / Differential protection trip signal. When the prevention mode is activated, the system will start the nitrogen injection with a time delay of 5 minutes.
- b. Extinction mode: To activate the extinction mode, the system needs to receive a linear heat detection signal + Buchholz relay / Differential protection trip signal. When the extinction mode is activated, the system will start the nitrogen injection instantaneously.
- c. Out of service mode: If the system receives only one signal (rubber disk rupture signal / linear heat detection signal / Buchholz relay / Differential protection trip signal) for 30 minutes, it will automatically switch to the out of service mode.

The Sergi firefighting system can be commanded through a control box usually mounted in the stations control room, close to the operational staff. The control box contains information that helps the staff be in permanent contact with the Sergi system.

5. CONCLUSIONS

The safety of power transformers is a matter of serious concern. Fire hazards lead into serious consequences such as fatal or non-fatal accidents and loss of electrical equipment. Protection devices are not always accurate and fast due to possible malfunctions or other technical matters so the need for multiple devices and functions is required as backup.

The Sergi nitrogen injection system is a reliable method of preventing and extinguishing fires on power transformers in comparison with an older, basic firefighting system.

References

- [1.] IEEE Guide for Protective Relay Applications to Power Transformers, Transformer protection Principles, Internet Article.
- [2.] www.electrical-engineering-portal.com, Power Transformer Protection Devices – Explained In Details, Internet Article.
- [3.] Siemens – Siprotec Differential Protection 7UT613/63x V4.60, Instruction Manual.
- [4.] www.electrical-engineering-portal.com, Transformer Winding Temperature Thermometer, Internet Article.
- [5.] Priya N. Gokhale, S.M. Bakre – Design of an inteligent nitrogen injection system for fire safety of power transformer, Internatiional Journal of Research in Engeneering and Technology, Volume 04, pages 536 – 541, February 2015.
- [6.] Sergi France, Sergi Transformer Protection, Instruction Manual, 01/27/2010.

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