Analysis of Fault Causes of the High-Voltage Oil Filled Electrical Equipment with Bellows

Sergey M. Korobeynikov
Power Engineering Department
Novosibirsk State Technical University
Novosibirsk, Russia
kor_ser_mir@ngs.ru

Leonid A. Darian
Department of Power Lines
Federal Grid Company FSK-EES
Moscow, Russia

Abstract— **The paper describes the results of analysis of hermetic current transformer faults briefly after installation. According to our estimations the main reason should be cracks in bellows filled by gaseous carbonic acid. This gas dissolves in the oil and transformer oil could moves inside the cracked bellow. That leads to catastrophic decrease in pressure in the apparatus and could produce bubbling in the parts with strong electric field. Partial discharges appear and could develop up to critical part discharge that leads to transformer breakdown.**

Keywords- Transformer oil, high voltage equipment, bubbles, partial discgharges, bellows, pressure drop.

I. INTRODUCTION

In the recent years an increased fault rate is being observed in the high-voltage oil-immersed electrical equipment (high-voltage oil-immersed electrical equipment, current and voltage transformers, high-voltage bushings, coupling capacitors), design of which provides sealed expansion bellows for compensation of transformer oil thermal expansion. Number of sealed bellows in every mentioned equipment type is specified by design features of a device and can vary from 2-3 up to 10-15. One of the most common methods for compensation of oil thermal expansion in sealed electric apparatus is in application of expansion bellows. In this case bellows are filled with gas and set inside oil volume. When oil temperature increases oil is expanded and consequently bellow is compressed. As a result pressure in the apparatus only slightly increases. When oil temperature decreases oil is compressed and thus it enables bellow expansion. Pressure in the slightly decreases.

The objective of this work is to analyze causes of accidents, in particular, faults in bellows sealing.

II. CONCERNING FAULTS DATA

A. Problem formulation

In Siberia there were installed 66 current transformers with bellows. Two transformers was faulted, 34 samples with enormous content of CO_2 was replaced. The typical picture one could see after examination of unsealed apparatus is presented on Fig.1.

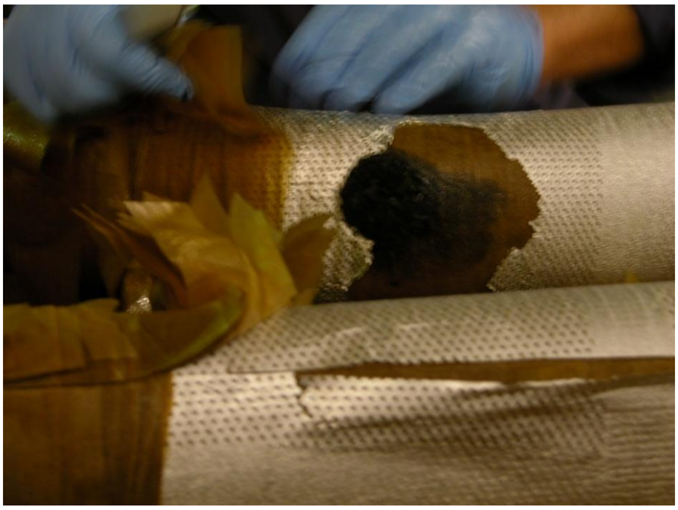

Fig. 1. The typical discovered defects after examination of unmounted transformers by producer.

What could conclude on the basement of visual inspection? Multiple carbonized defects point out partial discharges (PD). What is the reason of PD inception and why the conditions of PD inception arise? Why according to dissolved gas analysis there are a lot of carbon dioxide and increased amount of hydrogen?

B. Chemical reasons.

The explotable materials and their combinations were tested. The samples immersed in transformer oil were placed into thermostat and standed during 11 days at increased temperature.

Stainless steel have no influence on hydrogen appearance even at the temperature 130°C. Quartz sand presence leads to H_2 formation. The same result is due to material of welding in combination with wet paper.

- Sand content: SiO_2, minerals ilmenite $FeTiO_3$, zircon $ZrSiO_4$, rutile TiO_2, pyrite FeS_2.

Some reactions produced hydrogen

- $2\ FeS_2 + 15/2\ O_2 + H_2O \text{ --> } Fe_2(SO_4)_3 + 2\ H^+ + SO_4^{2-}$
- $Fe_2(SO_4)_3 + 6\ H_2O \text{ --> } 2\ Fe(OH)_3 + 6\ H^+ + 3\ SO_4^{2-}$

The CO_2 increase up to 800 ppm could be connected with presence of calcium carbonate into sand. But drastic change of the sand on more clean samples didn't solve the problem.

III. Evaluation of Apparatus Pressure in Case of Bellows Faults [1]

Let us assume that volume of transformer oil in the high-voltage oil-immersed electrical equipment comprises Vm. Total number of expansion bellows is - No. In this case number of undamaged expansion bellows is – N. General view of bellow upon its blowing is given on fig. 2.

Fig. 2. Bellow distortion upon pressure feed of 5.5 bar.

Let us assume that upon pressure decrease in the high-voltage oil-immersed electrical equipment the maximum permitted increase in expansion bellow volume, which is defined by its design and applied materials, will comprise ΔV.

Amount of gas Q in undamaged expansion bellow is determined through its concentration in expansion bellow - C_{g0} and bellow volume - Vc:

$Q =\cdot Vc\cdot C_{g0}$

When bellow is damaged a part of gas Q_m goes to transformer oil and dissolves in it. As a final result the molecular-kinetic balance between gas remained in unsealed expansion bellow - Qc and gas dissolved in oil is set:

$Q_m = C_m(T)\cdot V_m.$,

here $C_m(T)$ – gas concentration in transformer oil.

Aggregate gas amount in the high-voltage oil-immersed electrical equipment, i.e. in isolated system «gas-transformer oil» will be as follows:

$Q= Q_c + Q_m.$

In the general case with regard to number of expansion bellows in the high-voltage oil-immersed electrical equipment, the following formula is correct:

$$No\cdot Q= N\cdot Q_c + Q_m$$

The expression which determines gas concentration in oil and damaged bellows can be derived on basis of evident assumption that gas amount is permanent in the considered isolated system:

$$C_{g0}\cdot N_0\cdot V_c = C_g(T)\cdot N\cdot V_c + C_m\cdot V_{mo} \qquad (1)$$

where, $C_g(T)$ - gas concentration in damaged expansion bellow. Taking into consideration distribution of gases between fluid and gas phases through distribution coefficient K(T):

$$C_m(T) = K(T)\cdot C_g(T),$$

it is possible to determine gas concentration in damaged expansion bellow, and through it – to determine pressure in bellow. It also will specify pressure in the high-voltage oil-immersed electrical equipment. It is evident that when pressure decreases in the high-voltage oil-immersed electrical equipment, the stayed up expansion bellows will be expanded. For simplicity sake one could assumed that expansion bellows expand up to maximum volume $V_c+\Delta V$:

$$C_{\text{г}} = C_{\text{г}0}\cdot\frac{1}{1+\frac{(N-N_0)\cdot\Delta V}{N\cdot V_c}+K(T)\frac{V_m}{N\cdot V_c}} \qquad (2)$$

Taking gas pressure in expansion bellow to be in proportional to gas concentration $C_g(T)$, it is simply to derive expression which specifies pressure P in the high-voltage oil-immersed electrical equipment when one or more expansion bellows are damaged:

$$P = P_0\cdot\frac{1}{1+\frac{(N-N_0)\cdot\Delta V}{N\cdot V_c}+K(T)\frac{V_m}{N\cdot V_c}} \qquad (3)$$

One should note that although calculations assumed that transformer oil is the incompressible environment. However account for the latter is simple. The maximum change in oil volume through transformer oil compressibility can be evaluated according to the following estimation:

$$\Delta V_m = \frac{V_m\cdot(P_o - P)}{\rho\cdot c^2} \qquad (4)$$

where,

ρ- transformer oil density;

c – sound velocity in oil.

Taking formula (4) it can be readily shown that compressibility effect of transformer oil over pressure calculated values in the remained in the high-voltage oil-immersed electrical equipment can be neglected.

For demonstrative purposes the example of numerical calculation of pressure in the high-voltage oil-immersed electrical equipment upon seal failure in expansion bellows is given according to (3). Let us assume that expansion bellow with volume of Vc= 4 l is filled by carbon dioxide with pressure of 1 atm. Distribution coefficient K(T) for oil Nytro 11GX at 20^0C is 1.1 [2].

The parameters and number of bellows in electrical device are chosen from the next condition. The pressure inside equipment should be more then 0.5 bar at the lowest temperature -60^0C. If take into account the volume of transformer oil in current transformer V_m = 500 l, number of bellows в N_0 = 7, maximal bellows volume change ΔV = 0.4 l, and substitute these data in expression (3) one can get that at depressurization of single bellow the pressure inside device should be very low P ~ 0.007 bar, at depressurization of two bellows the pressure inside device should be P ~ 0.014 bar, three bellows - P ~0.021 bar.

It has been known that pressure decrease in the oil-immersed equipment insulation results in partial discharges growth, intensity of which increases as far as pressure decreases. The source of that state is micro-bubbles. Pressure decrease lower than 0.5 bar involves occurrence of critical partial discharges, followed by breakdown and electric explosion of the apparatus [3]. The special our experiments provided at real current transformer of the same model show that critical partial discharges appear at the low pressure $P \leq 0{,}15$ bar. Therefore one can conclude that after damage of one or several bellows and after establishment of gas equilibrium the pressure insude current transformer could be very low, that could lead to produce of critical partial discharges and electrical explosion of current transformer. The consideration of liquid head couldn't change this conclusion.

Therefore this work suggests mechanism for electric strength failure of the sealed oil-immersed equipment with bellows through catastrophic pressure drop in the oil-immersed equipment upon bellows seal failure.

CONCLUSION

The main reason of electric explosion of sealed current transformers with bellows was catastrophic pressure drop in the oil-immersed equipment after bellows failure, microbubbles appearance, partial discharges inside microbubbles, their size increase that leads to critical partial discharges and electrical insulation breakdown.

REFERENCES

[1] L.A. Darian, S.M. Korobeynikov "Evalution of pressure change in high voltage oil-filled equipment with sealed bellows". Electrical Technologies. - 2008, N.8, pp. 64-65 (in Russian).

[2] Buzaev V.V., Darian L.A., Sapozhnikov Yu.M. "Definition of distribution coefficient of gases dissolved in transformer oil". Electrical Stations, 2006, N. 12, pp. 58-63.

[3] Saiky J. "Causes of explosions in current transformers".SIGRE Symposium, 1987, N. 1020-01.