Operating Damages of Bushings in Power Transformers

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Abstract — **In the paper there are presented typical operating damages of bushings in transformers installed in the national power system. In the paper there are described the basic diagnostic methods for preparation of appraisal of technical conditions of a bushing installed in a power transformer. It is emphasized that it is necessary to increase the frequency of tests in the framework on ongoing control of the bushing technical state . The result of above is an increase of the transformer availability in the power system.**

Keywords — transformers, exploitation, diagnostic.

I. INTRODUCTION

Power transformers are one of principal elements of the power system. Operational reliability of power transformers is the important factor influencing operation of power systems. Maintenance of correct technical conditions of transformers is the subject of special care of their users. Statistics operating damages of power transformers installed in the national power system allow saying that in the last years defects of bushings were causes of several serious damages of transformers. Bushings are the element of transformer equipment. From point of view of reliable transformer operation they are extraordinary important elements of a transformer. From the world statistics one may say that defects of bushings make from 10 % to 40 % of total number of damages of power transformers. Most of bushings damages are sudden damages that may not be detected using *off-line* diagnostic methods. Transformer bushings used in power systems for voltage of 110 kV and more are mainly bushings with paper-oil insulation in the porcelain shield (bushing of OIP type). Recently in new transformers there are installed dry type bushings (bushings of EIRP type) with insulation made of paper impregnated using the epoxy resin in the composite shield, i.e. made of the epoxy glass covered by the silicone rubber. In case of explosion of EIRP type bushing practically no fire hazard exists and there is no danger related to the porcelain scatter. Composite bushings are also several times lighter than porcelain bushings. In reference to OIP type bushings estimated statistically service life when most of damages occur is between 15 and 25 years of operation. For 110 kV bushings the main cause of damages is occurrence of leakages. For 220 kV and 400 kV damages of dielectric type prevail where value of tg δ is increased; what in many cases leads to bushing explosion and in some cases to transformer fire.

In the paper there are presented basic diagnostic methods of bushing technical conditions appraisal and are presented bushing typical operating damages in power transformers installed in the national power system.

Table 1

Company	Bushing type ype	Loss factor tg δ_I [%]	
		typical value	warning value
ABB	O+C T	0.5	1.0
ASEA (ABB)	GOA 250 GOB. GOBK	0.5	0.7
	GOE < 800 kV	0.45	0.65
	GOE 800 kV	0.4	0.6
Passoni & Villa	PNO PAO	0.4	0.7
Bushing Co	OTA	0.35	0.6
Haefely Trench	COTA (BIL < 1400 kV) COTA (BIL > 1400 kV)	0.3 0.35	0.6 0.7

II. DIAGNOSTIC OF BUSHINGS

Diagnostic of technical conditions of OIP bushings in transformers installed in power system is based on the following measurements [6]:

- dielectric loss factor tg δ,

Table 2

company	tg δ at the 90 ^{0}C temperature [%]	breakdown voltage [kV]	water content [ppm]	conditions
Trench COS/COT	0,1	60	10	normal
	> 0,2	< 50	> 20	emergency

- capacitance C_x.

Measurements are performed using the following circuits:

- measurement of tg δ = tg δ_I and C_I capacitance in the circuit: the line terminal and the separated measurement terminal;
- measurement of tg δ_{II} and C_{II} capacitance in the circuit: the measurement terminal and the earthed line terminal or the insulator flange

and measurement of tg δ_{II} and C_{II} capacitance has secondary significance.

Direct appraisal of the bushing technical condition on the basis of tg δ_I and C_I capacitance measurement meets essential difficulties due [1]:

- influence of measurement conditions, mainly including temperature;
- variety of bushings types used in power transformers;

missing guidelines regarding uniform criteria of results appraisal of measurement performed in operational conditions. In Table 1 there are specified by manufacturer's criteria of technical conditions appraisal of bushings on the basis of the tg δ_I value[1].

Results of long term tests of bushings performed by Energopomiar- Elektryka Gliwice allow to assume tg δ_I = 0.7 as the limit allowed value guaranteeing correct technical conditions independently of bushings type [1].

Change of C_I capacitance of a bushing between 3 ÷ 10 % in relation to the factory value is usually assumed in diagnostics as a warning value for appraisal of bushing technical conditions [1].

Insulation arrangement inside the OIP type bushing consists of many layers of paper impregnated with oil.

Table 3

No	Characteristic gases	Typical examples of bushing defect	Type of defect
1.	H_2 , CH_4	discharges in cavities filled by oil in result of incomplete impregnation or high moisture of oil	partial discharges (WNZ)
2.	C_2H_2 , C_2H_4	continuous sparking in oil between incorrectly connected elements of different potentials	discharges with high energy
3.	H_2 , C_2H_2	sporadic sparking as result of transient potential or partial discharges	discharges with low energy
4.	C_2H_4 , C_2H_6	overheating of a conductor in oil	oil overheating
5.	CO, CO_2	overheating of a conductor being in contact with paper, overheating as result of dielectric losses	oil overheating

Therefore in diagnostics of technical conditions of such bushings it may be used methods for tests of paper-oil insulation of a power transformer:

- analysis of oil sample taken from the insulation bushing.
- frequency dielectric spectroscopy (FDS) of paper-oil insulation of a bushing.

These methods may be used after the power transformer disconnection from the power supply.

A. Tests of oil sample collected from a bushing include:

- analysis of gases in oil dissolved (DGA).
- physical-chemical tests of oil.

Analysis of gases dissolved in oil (DGA):

Tests of composition and concentration of gases disolved in oil allow detection of local defects of bushing insulation system. In Table 2 there are specified gases characteristics for specific defect of a bushing [1].

In appraisal of DGA results there are typical values of concentration of gasses in oil dissolved for normal and emergency conditions determined by bushing manufacturers.

In Table 3 there are specified values of concentration n of gases dissolved in oil for bushings of Trench company [2].

Table 4

company	hydrogen H_2	methane CH_4	ethane C_2H_6	ethylene C_2H_4	acetylene C_2H_2	carbon oxide CO	carbon dioxide CO_2	conditions
Trench COS/COT	140	40	70	30	2	1000	3400	normal
	> 1000	> 75	> 100	> 40	> 10	> 1500	> 5000	emergency

Physical-chemical tests of oil

Tests of dielectric and physical-chemical features of the oil and water content allow determination of oil condition in a bushing and appraisal of its moisture. In Table 4 there are specified tg δ values for oil from bushing, breakdown voltage and water content recommended by Trench company [2].

On the basis of measurements results of tg δ for bushing at two temperatures: 70 ^{0} C and 90 ^{0} C it is possible to detect occurrence of colloidal compounds arising during advanced processes of oil decomposition [1]. These compounds are especially dangerous for bushings because their conductivity is similar to metal particles conductivity therefore they cause increase of dielectric losses.

During temperature variations these compounds are dissolved and arise again. Therefore their occurrence influences temperature characteristics of tg δ. Value of the ratio tg $\delta_{90\ C}$ / tg $\delta_{70\ C}$ < 1.5 indicates occurrence of colloidal compounds, while value of tg $\delta_{90\ C}$ / tg $\delta_{70\ C}$ < 1.1 signals possibility of occurrence of sludge in bottom part of a bushing.

B. Frequency dielectric spectroscopy (FDS) – appraisal of moisture and ageing grade of the bushing paper insulation

The method of dielectric spectroscopy consists of determination of the following insulation system parameters: dielectric loss tg δ_I and C_I capacitance as function of frequency. This method may be used both for tests of a bushing and for collected oil samples. Determination of tg δ_I and C_I capacitance curves for frequency range of 0.1÷1000 Hz allows determination of moisture grade and development of ageing process of the bushing insulation system.

Obtainment of current information concerning technical state of the bushing requires making measurements of its parameters in *on-line* mode. *On-line* diagnostic and monitoring systems use capacitive or resistance sensors connected to measurement terminals of the bushing of the power transformer.

The most frequently measured parameter is leakage current [3]. Going analysis of leakage currents sum for 3-bushings at one side of a transformer (for example for transformer primary side) allows determination of bushings dielectric loss factor tg δ_I and C_I capacitance.

Quantities that subject to going appraisal are the following:

- unbalanced current of the sum of leakage currents – current amplitude and phase,
- relative change of tg δ_I factor,
- relative change of C_I capacitance.

Systems of *on-line* diagnostics of bushing technical state make as a rule part of the power transformer monitoring system where measurement data processing and presentation of obtained results is performed using a proper software.

III. DAMAGES OF BUSHINGS

Utilization of measurements of dielectric loss factor tg δ_I and C_I capacitance in technical condition diagnostics of the OIP type bushings is presented on the basis of 110 kV, 220 kV and 400 kV bushings damages that have led to serious failures of power transformers.

A. Damage of 110 kV bushing in 70 MVA power transformer

During normal operation of the power transformer insulation system in one of 110 kV bushings was suddenly degraded, earth fault occurred and next this bushing exploded (Fig. 1).

Fig. 1. Damaged bushing 110 kV in the 70 MVA power transformer

Pieces of porcelain from the exploding bushing damaged in some places porcelain of the neighboring two 110 kV bushings. Also the power lead from 110 kV winding (in the phase where bushing explosion occurred) was damaged.

Analysis of results of dielectric losses factor tg δ_I and C_I capacitance measurements of damaged bushing from last years of operation did not disclose exceeding of typical values allowed by the manufacturer. The scope of the transformer repair made at site has included replacement of 3-bushings 110 kV by new ones, repair of the damaged phase 110 kV lead and treatment of transformer oil.

B. Damage of 220 kV bushing in 160 MVA transformer

During operation of 160 MVA power transformer 220 kV bushing in L2 phase exploded. Damage of the bushing (Fig. 2) caused occurrence of single-phase short-circuit and fire at the transformer stand. Fire-fighting action was finished relatively quickly. After-failure tests of the transformer were made after installation of substitute 220 kV bushing in place of disassembled damaged bushing. Positive results of tests confirming correct internal state of the transformer decided that the decision was taken up concerning performance of transformer repair at the site. Porcelain elements of exploded 220 kV bushing made mechanical damages of 220 kV bushings of other phases and porcelain of 110 kV bushings and neutral point. Also porcelain of electric equipment in neighboring 110 kV field was damaged. As result of the fire accessories of the transformer were damaged and firing in some places of the tank occurred.

Fig. 2. Damaged bushing 220 kV in the 160 MVA power transformer

Analysis of results of dielectric losses factor tg δ_I and C_I capacitance measurements of the damaged bushing from last years of operation did not disclose exceeding of typical values allowed by the manufacturer .

C. Damage of 400 kV bushing in 250 MVA power transformer

During normal operation of 250 MVA power transformer explosion of 400 kV bushing in L2 phase and next fire of the transformer occurred (Fig. 3). Explosion of the bushing was caused by an earth breakdown in capacitance part. As a result of strong arc quick decomposition of oil in the bushing took place as well as sudden increase of the gas product pressure – of the oil decomposition.

Next the porcelain shield of the bushing exploded and ignition of oil and paper insulation impregnated with oil and next quick spread of transformer fire occurred. Impetuous development of fire was result of oil escape from the transformer tank. Probably in initial phase of fire oil escaped from the tap changer conservator via damaged oil level indicator that was smashed by porcelain part of the damaged bushing or broken as a result of high temperature of the burning oil. During the fire spread the tank was unsealed and oil flowed out via damaged coolers. Fire devastated the transformer completely together with its infrastructure – for example transformer gate, oil bowl.

Analysis of results of dielectric losses factor tg δ_I and C_I capacitance measurements of the damaged bushing from last years of operation did not disclose exceeding of typical values allowed by the manufacturer . Close before the 250 MVA transformer failure thermovision tests of temperature distribution at surface of 400 kV bushings were made.

Fig. 2. Damaged bushings 400 kV in the 250 MVA power transformer

Thermovision measurements of temperature distribution on the bushings surface showed differences between temperature distributions. The bushing 400 kV of L2 phase in comparison to other bushings showed highest non-uniformity of temperature distribution – approximately of 1.0 ° C. However it is impossible to say unequivocally that this non-uniformity of the temperature distribution on 400 kV bushing surface in "L2" phase could be the result initial failure condition of this bushing.

IV. SUMMARY

Prevention of serious failures of power transformers caused by defects of bushings requires increase of testing within current inspection of transformer technical state.

The basic method of OIP bushings testing is still measurement of dielectric loss factor tg δ_I and C_I capacitance. However, this method does not give full information concerning technical condition of the bushing.

In doubtful cases, when results of performed measurements are not unequivocal this method should be completed by other diagnostic method in the paper presented. *On-line* diagnostic systems of bushings technical state allow early detection of anomalies leading to deterioration of their technical state and radically reduce number of transformer switching off, necessary when bushings are tested using traditional methods. Use of dry bushings of EIRP type reduces risk of bushing explosion and occurrence of fire of a power transformer.

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