High-voltage electrical equipment with the SF6 (sulfur hexafluoride) gas insulation: analysis of accident rate and service experience

Alexander Yu. Khrennikov, Roman V. Mazhurin

Abstract— **The paper is devoted to the questions of exploring of high-voltage electrical equipment with SF6 insulation service. Analysis of the accident rate and basic causes of accidents are examined. There are discussed design deficiencies in different types of the current transformers, measures for their elimination, and inspections of the SF6 insulation current transformers by thermal-vision control, measuring the acoustic activity of the partial discharges (PD) into the insulation of transformers, the gas pressure in the housing, data of electrical tests, the results of analysis of the quality of SF6 by different methods. The quality standards of SF6 in the high-voltage equipment are accepted in accordance with IEC 60480–2004.**

Index Terms— high-voltage electrical equipment, substation, SF6 insulation, quality of SF6, accident rate

I. INTRODUCTION

More than 500 units of current and voltage transformers with voltage from 110 to 500 kV will be subject to the replacement into the near the years at Federal Grid Companies, Russia. A large quantity of substations is located in the stage of building or reconstruction, where the installation of SF6 insulation equipment, as a rule, everywhere adapts. The SF6 insulation equipment is much less flammable than fill with oiled. Nevertheless, SF6 insulation equipment has also a number of the deficiencies: with the combustion of the electric arc into SF6 insulation are formed the very poisonous compounds of fluorides, whose presence in the atmosphere presents serious problem for the health and ecology; with the repair work, connected with the decompression of the cavities, filled with SF6 insulation, it is necessary to use protective agents.

There is given design deficiencies in different types of the current transformers, measure for their elimination, and inspection of SF6 insulation current transformers by thermal-vision control, measuring the acoustic activity of the partial discharges (PD) into the insulation of transformers, the gas pressure in the housing, data of electrical tests, the analysis of the quality of SF6 by different methods. The norms of the quality of SF6 in the high-voltage equipment are accepted in accordance with IEC 60480–2004 and national standards [1]. Basic reasons for defects and damages of electrical equipment with the sulfur hexafluoride insulation: low mechanical strength, the low quality of SF6 insulation (increased humidity, the appearance of decomposition products of SF6), the unreliable fastening of protective hoods on the diaphragm devices, the defects of installation.

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II. ADVANTAGES AND DEFICIENCIES OF HIGH-VOLTAGE ELECTRICAL EQUIPMENT WITH SF6 INSULATION

SF6 (sulfur hexafluoride) gas is extensively used in the electrical industry for dielectric insulation and current interruption in high-voltage circuit breakers, switchgear, current and voltage transformers, and other electrical equipment. SF6 gas under pressure is used in gas insulated switchgear (GIS) because it is much more dielectric (non-conductive) than air or dry nitrogen, making it possible to significantly reduce the footprint and enable installation in constrained spaces.

The substantial part of the electrical equipment of substations, industrial enterprises, transmission system and electrical power distribution manufactured its resource, but it continues to be exploited, since large financial means be required to its replacement. In connection with this with each year the expenditures for conducting of complex inspections and diagnostics increase.

Therefore for a period of recent decades in the sphere of electric power branch we can observe number of positive changes, including in the plan of the improvement of the construction of electrical devices, increase in the period of the service of high-voltage electrical equipment, increase in the reliability with its operation.

Let us examine the main disadvantages in the traditional electrical equipment, which used earlier (air and fill with oiled):

- High coefficient of wear, often connected with the irreversible physical and chemical changes in the parameters of materials;
- Comparatively large overall dimensions and mass;
- Comparatively large required areas under its layout;
- Comparatively low stability to the short-circuit currents, especially under the conditions for the general development of power circuit;
- High expenditures and the volumes of maintenance;
- The complexities with the repair-setup works, which require the presence of the experienced, qualified personnel and specialists slender airfoil;
- High explosion- and fire hazard;
- Ecological danger;
- The complexities, connected with the acquisition of spare parts;
- More complex prompt service;
- Application of air high-voltage circuit breakers,

which requires the presence and the content of compressors, conduits and vessels; air high-voltage circuit breakers work under the pressure.

All this in the totality led to the qualitative jump in the technical development of the construction of electrical equipment, which received its expression in the application of electrical equipment with the internal gas basic insulation on the basis of SF6 (sulfur hexafluoride).

Together with the world experience, in the former USSR in 1960-1970-th years of past century were achieved the specific achievements in this sphere. Thus, in 1966 at All-Russian Electrotechnical Institute, Moscow, is created the division of sulfur hexafluoride equipment, the power transformer of 100 kVA with the SF6 insulation was in 1968 prepared and placed on the substation of Moscow metropolitan, was in 1974 prepared the first gas insulated switchgear (GIS) of 110 kV, and was in 1979 prepared the pole GIS of 1150 kV (Fig. 1).

Fig. 1 1150 kV gas insulated switchgear (GIS) at Togliatty Power Testing Laboratory, Russia, 1979.

This is already today in series produced practically entire spectrum of basic technological equipment with the filling, which contains SF6, wholly or in the mixture together with other gases (nitrogen). There were following types:

- Commutation equipment (high-voltage circuit breakers, compact devices, GIS;
- Transformer equipment;
- Instrumental current and voltage transformers;
- High-voltage bushings, high-voltage cable boxes, conductors, the gas-insulated electric power lines.

At today's moment it is also necessary to note presence on the market both of foreign and domestic firm-producers, who produce sulfur hexafluoride equipment as on the license of other firms, so the using and our own developments.

From the side of the organizations, which exploit power electrical equipment, also is manifested the tendency toward the installation of SF6 insulation equipment. In this case the corresponding special-purpose programs are developed. Thus, in Federal Grid Companies, Russia, in accordance with the appropriate programs of the replacement of equipment into the near years is subject to the replacement of more than 500 units of the measured current and voltage transformers (CT and VT) of the classes of voltage from 110 to 500 kV. Basic part (more than 80%) of those replaced CT and VT - 110 and 220 kV. Basic indices for the replacement - exceeding the period of service are more than 40 years, and due to the technical state (increased moisture content and/or the gas content of oil, increased magnitude of error and others).

In recent years on the substations of Federal Grid Companies, Russia, are put in service the new types of measurement current transformers, supplied by the domestic and foreign companies ABB, Siemens, Trench, Arteche, JSC “Electrozavod”, AREVA, Passoni&Villa.

In this case at today's moment the large number of substations is located in the stage of building or reconstruction. As a rule, the installation of SF6 equipment everywhere adapts on them (Fig. 2).

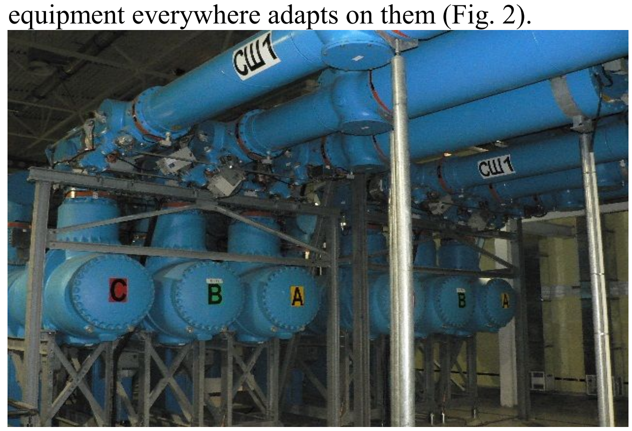


Fig. 2 Gas-insulated switchgear of 500 kV at electrical substation near Moscow.

SF6 insulation equipment, as it was said above, is much less flammable than fill with oiled. Internal damage in the SF6 measurement current transformer does not lead to the complete destruction of its insulator with the formation of the dispersion of its fragments and further damage of adjacent equipment, and ejection into the atmosphere of SF6, in contrast to oil, does not lead to the start of fire. SF6 measurement current transformers are considered as the explosion- and flame-resistant and this major advantage in comparison with the oil-filled transformers.

Nevertheless, SF6 insulation equipment has also a number of deficiencies. In particular, with the combustion of the electric arc in the atmosphere of SF6 are formed the very poisonous compounds of fluorides, whose presence in the atmosphere presents serious problem for the health and ecology. With conducting of the repair work, connected with the decompression of the cavities, filled with sulfur hexafluoride, it is necessary to use protective agents (glove and gas masks).

In the paper [2] of Electric Power Research Institute of Guangdong Power Grid Corporation, Guangzhou, China, during the long time track examination and disintegration to SF6 circuit breaker, the researchers obtained the massive monitor data. The criteria of resuming insulation discharge failure conforming to CSO2/CH2S>7, is quite broad to SO2 and the H2S concentration permission. Even if it reaches 100μL/L, it will not be in danger immediately to the safe operation of equipment.

Definite requirements are presented to SF6 insulation and also to other gases, with it mixed up. Sulfur hexafluoride in composition and to the chemical properties must correspond to requirements of IEC 60480-2004 [1]. Moisture content there must not exceed 15 ppm throughout the mass, which correspond 120 ppm on volume and the dew point minus of 40°C in Russian national standard. Nitrogen in composition and to the chemical properties must be the increased cleanliness and correspond to special requirements.

In addition to this, SF6 insulation equipment itself, as such, must satisfy the requirements of the reliability in service, maintainability, ecological, fire and electrical safety. The electrical substations of Electrical Grid Companies are located in practice throughout the entire territory of the Russian Federation, in the regions with the different service conditions, and the established equipment must equally reliably work both in the conditions of the extreme north and in the subtropical climate.

The basic condition of applying one or other type or another of electrical equipment in the grid companies - this is its certification.

III. ANALYSIS OF ACCIDENT RATE AND OPERATING EXPERIENCE

It should be noted that, in spite of all merits enumerated above, SF6 insulation equipment it is nevertheless subjected to failures and damages, especially because the internal active part of SF6 insulation equipment on its is structurally in many respects similar to the constructions of the equipment for the previous generations. The facts of the failure of SF6 insulation equipment in the process of service and the defects, discovered with its installation, are base for this assertion. It should be noted that that state aboved relates both to the production of foreign producers and to Russian developments.

Occurred the cases of the damages of SF6 insulation equipment, which were been prerequisites for their further modernization by the manufacturer (plant – producer). In particular, the discussion deals with the defect of the instrument current transformer of Russian production. Defect was expressed in the spontaneous break of the membrane, as a result of the unreliable fastening of protective hood, and untwisting of lateral screen on the active part of current transformer during the transportation of it (Fig. 3).

Fig. 3 Defect of the instrument current transformer - the break of the membrane.

On this case were accepted the following steps (Fig. 4):

1. The purchase of the current transformers of this type with the voltage of 110 and 220 kV was temporarily stopped;
2. With plant - producer introduced the appropriate design changes - was changed the construction of diaphragm device and the method of fastening lateral screen (with the aid of the welding);
3. The replacement of diaphragm devices to those modernized is conducted on the established current transformers;
4. The plant- producer supplies the modernized current transformers at this moment.

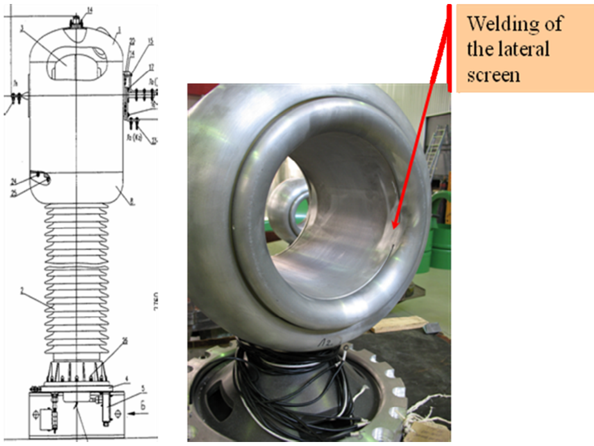


Fig. 4 The modernized current transformer.

The cases of damaging the high-voltage instrumentation equipment with its transport because of the insufficient mechanical strength of its elements also occurred. In particular, the damage of SF6 insulation current transformer occurred with the transport (it occurred the destruction of the insulating supports, which support screen). Damage was revealed in the process of installation (Fig. 5).


Fig. 5 Damage of SF6 insulation current transformer with the transport.

Design deficiencies in this type of current transformers were the reasons, which prevent their application. Was recalled expert conclusion to the current transformers of this type for 362 and 550 kV and complete prohibition to their purchase and use was introduced.

IV. DIAGNOSTIC METHODS OF INSTRUMENT TRANSFORMERS WITH SF6 INSULATION

In fig. 5 are given the basic methods of complex diagnostics of instrument transformers with SF6 insulation [3]. These are thermal-vision inspection, the measurement of the acoustic activity of the partial discharges (PD) into the insulation and the analysis of the quality of SF6 by different methods [3, 7, 8].

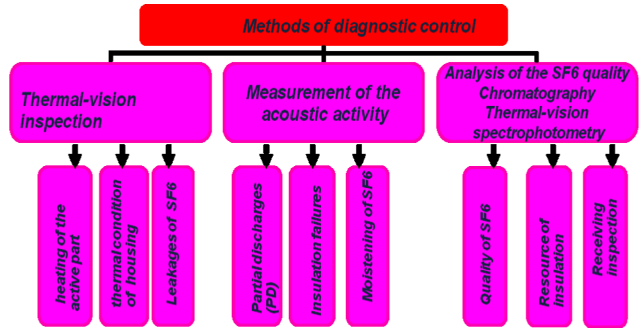
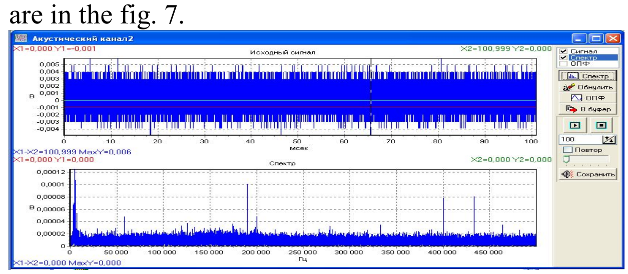


Fig. 5 Basic methods of complex diagnostics of instrument transformers with SF6 insulation

Thermal-vision inspection is very effective for predictive diagnostic for SF6 insulation current and voltage transformers, and it is achieved in accordance with national standard RD 153-34.0-20.363-99 "The basic condition of the procedure of infrared diagnostics of electrical equipment and transmission airlines" (Fig. 6).

Fig. 6 Heat-gram of SF6 insulation current transformer (ΔT=2,1 oC).

An acoustic activity of the partial discharges (PD) into the insulation of SF6 insulation current and voltage transformers is one of the basic methods of complex diagnostics. Acoustic signals of PD into the insulation of SF6 insulation current transformer and their spectra are in the fig. 7.


a) AA= 0,9 dB;

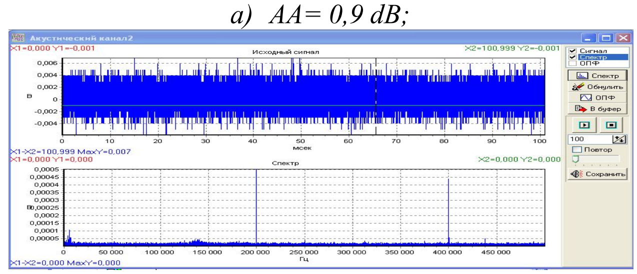

b) *AA= 50,3 dB*

Fig. 7 Acoustic signals of PD into the insulation of SF6 insulation current transformer and their spectra

Normative documentation during PD measurements are national standard GOST-20074-83 "Method of measuring the PD characteristics and IEC-60270 "The measurements of PD characteristics" [8].

Compositional analysis of SF6 is carried out by spectrophotometry by portable dissolved multi-gas analyser TRANSPORT X (fig. 8).

Analysis of a transformer oil sample for dissolved gases by a laboratory is an established technique recognized as the most important test for monitoring power transformers.

The Kelman TRANSPORT X is a compact portable Dissolved Gas Analysis (DGA) system which can be used to analyze oil samples for all dissolved fault gases and moisture. If abnormal levels are detected, it further provides a diagnostic using various IEEE/IEC approved interpretation rules.

This is a vital piece of equipment when more frequent oil tests need to be performed on aging transformers or when an immediate on-site diagnostic is required following an alarm from a single gas DGA monitor.

Normative documents and national standard is RD-16.066-05 "Sulfur hexafluoride electrotechnical equipment technical requirements for the production" and IEC 60480-2004.

Fig. 8 Compositional analysis of SF6.

But if the damage of electrical equipment with the SF6 insulation occurred, then work on release from the tank of contaminated sulfur hexafluoride to the atmospheric pressure is produced on the spot the installation through the neutralizing solution, the works on the dissection of tank - in the specially equipped accommodation of substation.

Presence in air even of small quantities of gaseous decomposition products of SF6 has the following signs:

- Caustic or unpleasant smell;
- Irritation of the mucous membrane of nose, mouth, eyes, etc.

These signs are observed immediately and it is considerably earlier than any toxic reaction. If caustic or unpleasant smell is discovered, personnel must immediately leave the accommodation, which then must be thoroughly ventilated.

The widespread introduction of SF6 insulation electro technical equipment, in particular, GIS, advances the increased requirements for the guarantee of their safe service. Into composition of GIS enter the extensive busbars and the separate apparatuses: circuit breakers, instrument transformers with the significant number of mechanical connections with the high demands for their air tightness.

The most usual defect of SF6 insulation apparatuses is the loss of their air tightness, expressed in the increased leakage SF6. For eliminating this malfunction the periodic completion of apparatuses by SF6 is produced. Because of the high density, this gas possesses properties to be accumulated in the lower and weakly ventilation accommodations, displacing air, which presents significant danger to the personnel.

Hexafluoride of sulfur SF6 is one of the most active greenhouse gases, the index of greenhouse effect of which is more than four orders higher than the carbon dioxide, which necessitates the decreasing of its unfavorable ecological actions on the environment. Interaction SF6 with the water in the electric field of crown or arc discharge leads to the formation of hydrofluoric acid and sulfur compounds, which possess high corrosiveness with respect to the glass and ceramic insulators and the metal insert. Not last factor is economic component, connected with the need for the continuous completion of apparatuses GIS by expensive SF6.

At present the search for the places of leakages SF6 in the GIS apparatuses is produced by the local sensors (leak detectors), with a comparatively low productivity. It should be noted that the fixed systems of control be absent on some types of SF6 equipment. For purposes of warning emergency failures, similar apparatuses are equipped with the simplified signaling apparatuses of the loss of pressure of SF6. The development of new methods and means of the operational control of the leakages of SF6 with their introduction GIS in service and with the operation is the important task, the urgency of solution of which will grow in proportion to the expansion of the introduction of these devices.

The large part of the electrotechnical equipment, which today is used in the Russian industry, is obsolete or exhausted its production resources. At present in the energetic enterprises of the country occurs the replacement of this equipment, and one of the basic requirements, which are presented to the new equipment, is its correspondence innovation by strategies of the development of branch. In other words, equipment must be contemporary, highly technological and safe. Special requirements are presented to the safety - under production conditions the risk of the appearance of fire or explosion is always high. Therefore basic rates are done to the SF6 current transformers - newest development in the field of electroenergetic. They possess a number of merits and advantages in comparison with other alternative equipment.

The use of SF6 current transformers in enterprises makes it possible to substantially reduce the dimensions of accommodation, and also the total area, which the substation occupies. SF6 transformers have very high efficiency with the operation on the substations, located in the large cities, where the cost of the lease of the section of the earth appears sufficiently high [9].

CONCLUSIONS

The results of the carried out complex inspection showed that the basic reasons for the failure of instrument transformers they are the low quality of SF6 (sulfur hexafluoride), design deficiencies in the transformers, the absence of absorbers for adsorbing of moisture and decomposition products of SF6, the application of not corrosion-resistant materials for manufacturing the transformers and the low quality of service maintenance [3-9]. The quality of SF6 must correspond to the norms, indicated in IEC 60480-2004.

In spite of is the fact that accumulated comparatively small experience of the SF6 equipment's service, it is possible to make basic conclusions about the reasons for its damages and weaknesses. Basic reasons for defects and damages of electrical equipment with SF6 insulation:

- Low mechanical strength of elements and articulations, which leads to the destruction of the internal elements of construction during the transportation;
- Application of materials, which do not possess required corrosion resistance;
- Low quality of SF6 (increased humidity, the appearance of decomposition products of SF6);
- Unreliable fastening of protective hoods on the diaphragm devices;
- Defects of installation;
- Low quality of service maintenance [4-7].

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