Gas-Insulated Metal-Clad Switchgears Express-Diagnostics Method on Partial Discharge Characteristics

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Abstract: - This paper describes a method for the express diagnostics of gas-insulated metal-clad switchgears (GIS) based on the characteristics of partial discharges. The research objects in this work were GIS of 110 kV and above. The subject of the research were methods of detecting partial discharges (PD) in GIS and high-voltage bushings of the air–SF6 type, interpreting the measured signals for selection from interference, locating the PD seat, determining the type of defect and assessing its danger for continued operation. The purpose of this work was to improve the diagnostic method for GIS in operation based on the PD characteristics. In the framework of this research, physical and mathematical modeling of the devices protecting the signal from external interference and measuring the PD characteristics in the laboratory and in operating conditions were carried out; digital methods of analysis and processing of PD signals were used.

Key-Words: - gas-insulated switchgear, partial discharge, technical diagnostics, express diagnostics, SF6 gas.

1 Introduction

Nowadays in modern power engineering gas-insulated equipment is increasingly being used for new construction and renovation: switchgear, high-voltage switches, current and voltage transformers, gas-insulated transmission lines, power transformers [1]. The equipment with SF6 insulation is highly reliability, has compact dimensions, low fire risks, environmental safety and other benefits.

The weakest elements of GIS are breakers and disconnectors. To a lesser extent, the switchgear rooms as a whole, voltage transformers and air–SF6 bushings are damaged. In most cases, the insulation structures of these elements fail, and in turn, their damage and aging are in many ways due to the influence of partial discharges (PD).

GIS have a number of insulation problems despite the high reliability:

• by-products of SF6 gas decomposition by the arc and PD;
• environmental hazard of SF6 gas;
• high-frequency overvoltages in commutations;
• reliability of support insulators;
• contamination of SF6 gas with metal particles.

Many installation errors and inadequate quality assurance procedures can lead to high-intensity PD that, in the presence of moisture, cause toxic by-products of SF6 gas.

Typical GIS faults are:

• SF6 gas leakage;
• contamination of SF6 gas with metal or dielectric particles;
• contamination of SF6 with arcing products;
• roughness, protrusions and burrs on conducting parts;
• internal defects of supporting insulation in the form of gas cavities, peelings or cracks.

With the exception of leakage, all other faults are potential seats of the PD occurrence and, accordingly, can be detected when detecting certain characteristics of the PD.

For these reasons, the development of low-cost, effective and non-destructive diagnostic methods for partial discharge identification in gas-insulated switchgear is of crucial importance.

2 Partial discharges

The PD is a localized electrical discharge inside an insulating medium located between two electrodes. Various types of discharges, such as the corona, electron avalanche, multi-avalon (Townsend) discharges, streamers, barrier discharges and microdischarges in the impact of charged particles can be attributed to the PD. The PD is a very complex phenomenon that has a chaotic, non-stationary or fractal type of behavior with unpredictable transitions between different physical mechanisms. The confusion in the classification of PD mechanisms is a consequence of the diversity of geometric, physical and chemical factors affecting the PD.

In most of the cases considered, the PD is a gas discharge in the cavities of a solid dielectric. The type of dielectric can affect the behavior of the PD due to the formation of secondary electrons or changes in the local field because of the accumulation of surface or space charge. Essentially, the PD process can be described by a system of differential equations. In general, the PD model should include both physical and chemical processes associated with changes in the properties of the medium and the dielectric at the PD location and leading to a change in the PD behavior.

Now, the PD recording has become an obligatory element of quality control of GIS elements at the manufacturing plants and quality control of the GIS assembly in the pre-start tests. As practice shows, the PD intensity indicates the state of GIS insulation also in the process of operation. It is noted that the PD intensity begins to rapidly increase to (20 – 100) pC a few days before the failure.

Today, acoustic, electric, electromagnetic and chemical methods are used to record PD in GIS.

3 Express-diagnostics of Gas-insulated Switchgear

Currently, the most common methods for registration of partial discharges in gas-insulated switchgear include taking out of service for repair and diagnostics or the installation of a real-time stationary partial discharge monitoring system. Both options presuppose significant financial costs [2]. For these reasons, the development and implementation of new non-destructive control methods of the gas-insulated switchgear are of great importance. Based on the analysis of national and foreign practical experience, the following key steps of the diagnostics were identified:

- analysis of main design solutions of the switchgear;
- selection of the type and location of partial discharge sensors;
- providing measures against external and internal interference;
- identification of partial discharge source location;
- identification of possible causes of partial discharge effect occurrence;
- determination of the danger rate of the partial discharges;
- providing recommendations for further actions.

3.1 Gas-insulated switchgear

Before starting the diagnostics, when analyzing the design of the switchgear, special attention is paid to the following aspects [3]:

- the type of the switchgear assembly;
- constructive design of separate modules connection of gas-insulated switchgear;
- the presence of radio-transparent windows in the shell of the switchgear;
- the presence of inputs "cable - SF6";
- the presence of air-gas-insulated inputs with condenser type insulation;
- the presence of built-in sensors of partial discharges (inductive, capacitive, electromagnetic).

3.2 Partial discharge sensors selection and allocation

Based on the analysis of design features of the gas-insulated switchgear under consideration, types of sensors and a list of places suitable for partial discharge registration are selected [4]:

- built-in capacitive partial discharge sensors;
- high-frequency current transformers (HCTT) on the grounding conductors of cables' shields, grounding of cones of cable glands or testing air-gas-insulated inputs;
- add-on electromagnetic sensors on dielectric windows;
- add-on electromagnetic high-voltage or ultra-high-voltage sensors on dielectric belts at the junctions of modules;

• acoustic sensors on the surface of the switchgear shell.

The calculation of the optimal number of partial discharge sensors, which is necessary for effective control of the entire internal volume of the gas-insulated switchgear, is carried out according to the following expression:

$$D_{PD} = 3 \cdot N_{inp} + T_{GIS} \cdot N_{bus} \quad (1)$$

where N_{inp} – the number of gas-insulated switchgear inputs; N_{bus} – the amount of switching points of gas-insulated switchgear buses; T_{GIS} – gas-insulated switchgear design (for single-phase – 3, for three-phase – 1).

The proposed approach requires 3-4 times smaller number of partial discharge sensors, than in case of each gas-insulated switchgear compartment control.

3.3 External and internal interference reduction methods

The problem of transmitted signal protection from induced interference is solved using a developed fiber optic channel, the functional diagram of which is shown in Figure 1. The fiber optic channel includes the following elements [5]:

• transmitter that converts the electrical signal at the output of the discharge sensor;

• signal transmission channel - fiber-optic communication line;

• receiver - a device, that converts an optical signal into an electrical signal.

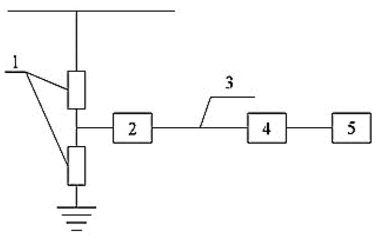

Fig.1. Fiber-optical measuring channel: 1-sensor, 2-transmitter, 3-fiber-optic link, 4-receiver, 5-recording device

3.4 Partial discharge source identification

Firstly, it is necessary to identify whether the source of the partial discharge is inside the object under consideration or outside it. When performing express diagnostics, the switchgear is not taken out of the operation, therefore, it is not an isolated object and it is connected to other substation equipment by means of cable links or by means of busbars via air-gas-insulated inputs.

The second step is to determine the location of the partial discharge source inside the switchgear. It is made on the basis of time tag comparison of the signals, arriving to separate sensors of the metering circuit (Figure 2).

The distance X between the sensors is calculated from the design drawings of the switchgear. Then the distance between the partial discharge source and the first sensor is calculated according to the following equation:

$$X_1 = \left[X - \left(X_1 - X_2 \right) \right] / 2 = \left[X + c \cdot \Delta T \right] / 2 \quad (2)$$

where X – the distance between the first and the second sensor, X_1 – the distance between the partial discharge source and the first sensor, X_2 – the distance between the partial discharge source and the second sensor, c – electromagnetic wave propagation speed c=0,3 m/ns, ΔT – the difference between the time tags of the sensors.

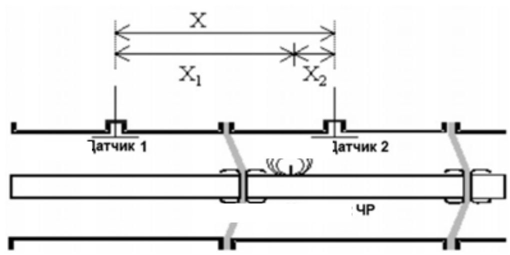

Fig.2. Identification of the distance between the sensor and partial discharge source in gas-insulated switchgear

3.5 Determination of possible causes of partial discharge and the danger level for the subsequent operation

Depending on the location of the partial discharge source, it is possible to determine the potential causes of its occurrence, as described in Table 1.

Table 1. Partial discharge causes

Partial discharge source	Defect description
Located in the junction of the compartments of gas-insulated switchgear	A typical source of partial discharges are microcavities or microcracks in support insulators separating the compartments of gas-insulated switchgear
Located near the module, containing a current or voltage transformer	The potential source of the partial discharge is the damaged insulation of the current or voltage transformer
Located near the cable or overhead wire input	The potential source of the partial discharge is the end of the input "cable - SF_6 gas" or the input "air - SF_6 gas"
Located near the busbar module, which does not contain any additional equipment	Potential source of partial discharge is free metal particles

4 Case Study

The validation of the developed method of express registration of partial discharges is carried out on the basis of diagnostics of the technical state of a 220 kV SF6 switchgear at 220 kV Substation Vlasikha in Barnaul, Russia. Measurements for partial discharges identification was carried out using high-frequency current transformers RFCT-4 manufactured by Dimrus and a digital oscilloscope Tektronix DPO3014. The following measurements were made:

• synchronous measurement of the signals from different points of sensors connection on the cable entry;

• synchronous measurement of signals on the grounding of the cones of the three phases of the "cable-SF6" inputs;

• synchronous measurement of signals on the grounding of the cones of all cable inputs, separately for each phase.

The identification of the source of the signal within the diagnosed object was determined using a time-of-flight (wave) method. The results are shown in Table 2.

Table 2. First negative peak parameters

Channel	Peak recording time, ns	Signal arrival delay relative to the time of the first registration, ns	Signal amplitude, mV
1	129592.8	0.4	26.78
2	129592.4	0	28.19
3	129737.6	145.2	3.23
4	129660.0	67.6	2.76

The calculation of the signal travel time and the distance from the source of partial discharge to the sensor 2 is carried out according to (3):

$$T_2 = \left[L/c + \Delta T \right] / 2 , \; X_2 = \left[L + c \cdot \Delta T \right] / 2 \qquad (3)$$

The propagation velocity of the signal was assumed to be equal to the speed of light c = 299792458 m/s. Based on the design documentation, the distance between the sensors of the 1st and 2nd channels was determined, where the signal from the partial discharge source was initially detected L = 18 m. The running time to the second channel sensor was T2 = 28 ns, which corresponds to a distance of 8.4 m.

The most accurately recorded signal (Figure 3) in terms of the amplitude and the shape corresponds to the oscillogram obtained for the defect model "current conductor protrusion - shell of the switchgear", combined with dielectric particles in the discharge gap (Figure 4). The cause of the protrusion appearance on the conductor can be the low quality of surfacing of the current conductor during production or the damage, obtained during installation of the switchgear. Dielectric particles inside the pressurized shell of the switchgear compartment is usually a metal dust, that appeared inside the shell during installation works. Such dust is usually concentrated around the increased electric field strength. The apparent charge of partial discharges calculated from the oscillogram is 4.98 pC. The following conclusions can be drawn:

• The source of partial discharge is a small protrusion on the current conductor, possibly with the presence of free dielectric particles in the discharge gap.

• The apparent charge of the partial discharge does not exceed 5 pC and in accordance with [6] does not exceed the marginal level for the equipment.

• The equipment is in a good technical state, further operation is possible.

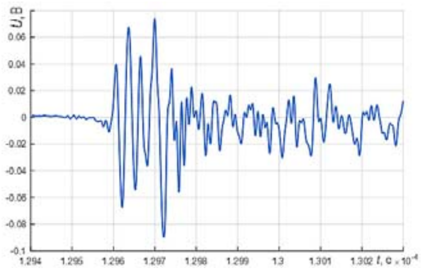

Fig.3. Oscillogram of the signal registered inside the switchgear

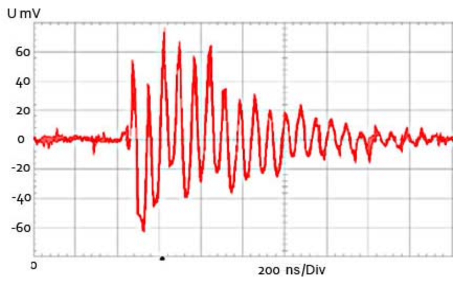

Fig.4. Signal template of the defect "protrusion on current conductor gas-insulated switchgear shell "plus dielectric particles

5 Conclusion

The gas-insulated equipment has established itself as a reliable and technological alternative to equipment with oil or air insulation. However, the relatively high cost restrains its widespread introducing into operation. At the same time, new equipment requires more careful monitoring of its parameters, which contributes to the development of new methods for monitoring and diagnosing the technical state and improving existing ones.

Diagnostics or monitoring of the technical state of gas-insulated switchgear requires the control of the pressure of SF6 gas and its properties, as well as the detection and assessment of the number of defects on the basis of partial discharge intensity records. Most of the types of partial discharge analysis are carried out in the framework of commissioning tests at the installation site of the switchgear, and the installation of continuous monitoring systems requires additional capital investment.

The possibility of using the developed methodology for the operational recording of partial discharges in GIS is checked in practice.

New methods of simulating the partial discharge for calibrating the registration system are proposed. In practice, the possibility of using the developed method of express registration of partial discharges in the switchgear is verified.

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