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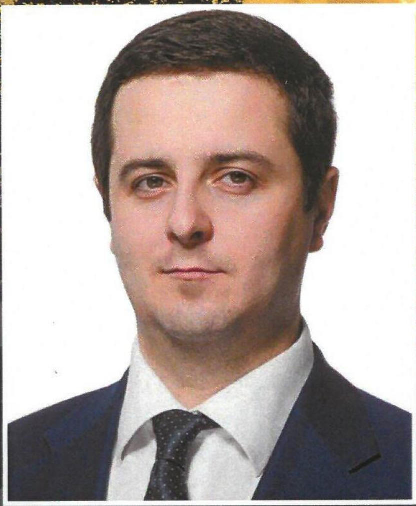

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One of the main Federal Grid Company (FGC UES) task is the reliable consumer electricity supplying. In this respect the electrical grid system modernization using the state of the art scientific-technical developments is carrying out by FGC UES. The International Council on Large Electric Systems (CIGRE) is one of the main forums participation in which encourages the industry international developments trends generalization, the actual questions in the electrical energy industry solution. Cooperation with the foreign colleagues makes possible to the FGC UES experience exchange, competence extend, and as a result, to be the leader in the innovation implementation part.

Diagnosis of conductors with cast insulation

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In recent years the conductors with cast insulation are applying on electric power stations and substations. The application scope of such conductors in Russia is limited by voltage 35 kV, and abroad – by 170 kV. Rated current of the conductors reaches 12 kA. In domestic practice and foreign practice, phase-isolated cast resin insulated busbars (PICRIB) with a voltage of more than 1 kV, designed for application in indoor and outdoor electrical installations, are widely used.

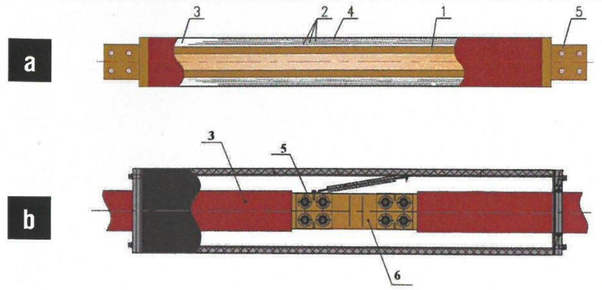

Fig.1 — Section (a) and coupling (b) of PICRIB construction

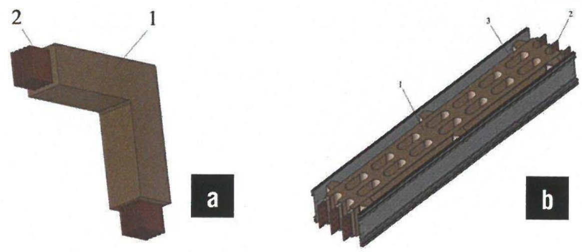

Fig.2 — CRIB conductor sections:
a) L-shaped section with voltage up to 1 kV;
b) a straight section with a voltage of 10 kV

PICRIB consists of single-phase sections (straight or with turns), up to 10 m in length. Couplings are mounted betweeen the conductors sections. Current conductors can have protective casing (mandatory for outdoor installations) made of corrugated polyamide, stainless steel or aluminum.

Current-carrying buses 1 of the current conductors (Figure 1 a, b) are made of aluminum alloys or copper ring (tube) or round (bars) cross-section. Contacts 5 are provided at the ends of each bus current lead section. The insulation 3 of the current lead sections is made of creped paper and epoxy compound. Semiconducting layers as well as grounding layer 4 are provided for equalizing the potential inside the insulation of sections. Sections of each current lead phase are connected by the temperature deformations compensators 6 (Fig. 1b), usually of the plate type. Depending on the voltage level, couplings can be air-insulated without semiconducting layers (up to 12 kV) and with semiconductive layers (up to 72.5 kV) or oil insulation with semiconducting layers (above 72.5 kV). The equalizing plates of each section and the couplings of the PICRIB are grounded.

PICRIBs are intended for transmission, and power distribution, in case of using T-shaped couplings (and, accordingly, they operate as a conductors, as well as, if necessary, as a switchgear busbar). PICRIB insulation is designed for operating voltage and provides the necessary level of electrical safety during operation. Current conductors can be made for cable routing of various configurations, compact in configuration and useful for cabling in confined spaces. They are manufactured for indoor and outdoor electrical installations, various climatic regions and operating conditions [1], can be used in marine climate conditions, as well as in areas with unfavorable atmospheric conditions (for example, near metallurgical, petrochemical plants etc.). PICRIB installation does not require welding. Conductors up to 72.5 kV are fire and explosion-proof. In addition, PICRIBs have sufficiently high electrodynamic and thermal withstandability, can be used in seismically active regions and do not require additional cooling.

Current conductor cast resin-insulated bushing (CRIB) is formed from sections of the current conductor of various geometric shapes (straight or L-, T-Z-shaped section). The length of section, as a rule, does not exceed 4 m. Depending on the rated voltage level, section of current conductor may contain two (for DC) or three medium voltage busbars and up to five current-carrying busbars for alternating current with voltage up to 1 kV (Figure 2). Each CRIB section presents an aluminum (or copper) bus of the two corresponding geometric shapes bathed in epoxy resin 1 (Figure 2).

The ends of the buses in sections are free and allow the connection between two different sections, wherein the junction of sections is subsequently also filled with an epoxy compound. The construction of CRIB sections for medium voltage range provides for additional cooling of the buses by means of through-holes 3 (Figure 2) between the adjacent phases. Medium voltage bushing sections, filled by epoxy resin, allow metal casing of a current conductor mounting. A metal casing with holes is provided for the internal installation of CRIB, and with a solid surface — for outdoor installation.

The connection of CRIB to the electrical equipment is carried out by means of special terminal elements, which are manufactured individually depending on the type of equipment and the method of connection.

It should be noted that PICRIBs have a relatively high cost compared to CRIBs. In both types of current conductors, a large number of bolted connections of current-carrying elements are used; the insulation of current conductors does not allow significant mechanical stress (shocks, impermissible loads, etc.). Disturbances during transportation, rigging and mounting works, storage and operation conditions can lead to (in some cases, already resulted in) faults in current conductors. As a result of such violations, as well as (in rare cases) violations in manufacturing technology (rejected equipment), defects of contact connections, solid insulation, loss of contacts of equalizing plates and grounding of current leads have occurred.

The required training of installers, increased supervision by the chief engineers in the course of mounting works, strict adherence to instructions for transportation, storage and operation is one of the directions for improving the reliability of current conductors.

It is also necessary to effectively monitor the technical condition of conductors with cast insulation after installation and during operation. It should be noted that the requirements for diagnostic monitoring of cast-iron conductors, as well as other new equipment, absent in standard 34.45-51.300-97 [2]. Control tests of current conductors recommended by manufacturers are not always effective and sufficient for trouble shooting (including putting current conductors into operation).

Operational tests (including post-mounting tests) recommended by manufacturers and suppliers of current conductors include an overvoltage test, DC resistance measurements and, in some cases, thermal imaging control. It should be noted that the recommended methods (except thermal imaging) require putting the current conductor out of work. In addition, the supply of high test voltage is a destructive

Fig.3 — Current conductors with cast insulation 6 kV:
a), b) — PICRIB type; c), d) — CRIB type

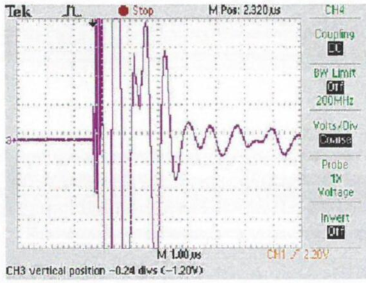

Fig.4 — Waveform of the spark discharge pulse with a scan of 1 µs/div., registered by sensors — high-frequency transformers with a ferromagnetic core, placed on a grounding wire of phase A screen conductor

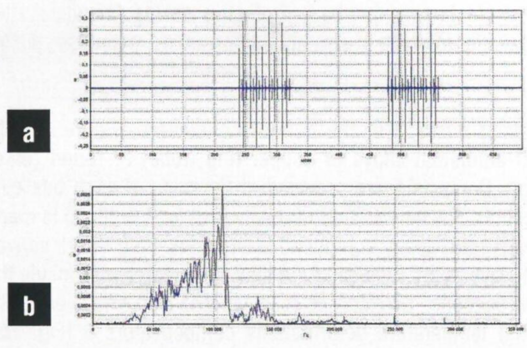

Fig.5 — Pulse waveforms (a) and spectrum of acoustic signal (b), recorded by contactless method (microphone) at the moment of sparking in a coupling of PICRIB conductive phase "A"

method of monitoring the technical condition. The effect of high voltage test (especially with a long service period) can provoke the development of the partial discharge (PD) in epoxy-paper insulation, which could lead to the insulation breakdown in the remote future after the tests. Moreover, operating experience shows insufficient effectiveness of recommended methods for detecting electrical defects related to the development of partial discharges of insulation, as well as electrical sparks in various contact connections (including potential equalizing plates and grounding system).

Examination and measurement of the electrical discharges in current conductors with a voltage up to 6 kV (Figure 3) on the substation under operation were carried out to determine whether the diagnostic monitoring and check of various methods and instrumentation systems are really effective to finding defects in current-carrying conductors with cast insulation under operating conditions.

It should be noted that periodic crackling, peculiar for electric discharge, was noted on a coupling of the current conductor, prior to the carried out survey of PICRIB current conductor (Figure 3a, b), which in the dark room gave a light reflection. High voltage tests did not clearly diagnose the location of a defect. The expected defective coupling phase B was dismounted and replaced for a new by specialists of the current conductor manufacturer. Later on at disassembling of this dismounted coupling at the factory, no defects were found. Other types of works in the area of dismounted coupling have not been documented. (However, transfer of the ground conductor from one end of coupling of the adjacent phase to the other end of coupling cannot be excluded). A few days after repair, the discharge phenomena were again registered by the operating personnel. Repeated high voltage tests of all phases of the current conductor did not lead to breakdown. No-load operation of the current conductor was continued.

The investigation was carried out in the no load mode of the current conductor. The following works were performed to find defects:

- measurement of partial discharges and other electrical discharges using high-frequency transformers (tongs sensors) mounted on the grounding wires of the equalizing plates (screens) of the sections and couplings of the current conductor;
- location of the partial discharge by the acoustic method;
- location of the partial discharge in the insulation of current leads by electromagnetic (noncontact) method along the length of the current conductor using a high-frequency scanner and various types of antennas (induction sensors).

Examination revealed two types of useful signals, caused by two different defects. So flashing was recorded in one of the couplings of phase "A". The discharges were fixed by all measuring methods (Figures 4, 5 and 6a, b) and appeared periodically with an interval of 1-5 min. and more. Defective phase was identified by the signal level.

Detected flaw was visually observed from the phases "B" and "C" side in the upper part of the coupling in the connection zone of the aluminum flange to the coupling body. According to the obtained results analysis (which was confirmed by subsequent disassembly and inspection of the coupling), spark discharges are caused by the loss of contact between the aluminum flange and the equalizing potential plate.

In addition, stable (regular) discharge processes (partial discharges), which maximum intensity is shifted with respect to spark discharges in phase A by 120 (60) electric degrees approximately were recorded by means of electromagnetic location (Figure 6b, c) and by electric method (Figure 7). It is instrumentally detected that the level of discharges in the area of the current carrying conductor with the defective

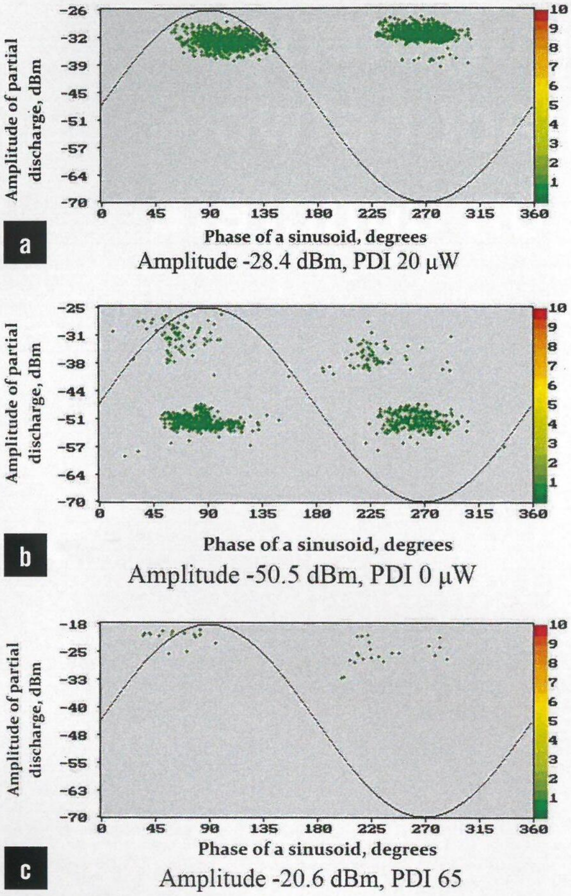

Fig.6 — Amplitude-phase distribution of pulses recorded by a high-frequency scanner at the moment of arcing in screens (a, b) and in the absence of sparking (c). Curve of industrial voltage frequency is obtained from 0.4 kV network and is not referred to phase under investigation

coupling decreases in one direction of current conductor and increases in the other direction closer to the adjacent cable room 6 kV No. 4. The signal is fixed and in some other rooms of the 6 kV switchgear. The source of partial discharge is unambiguously not established, since there was no organizational possibility to make measurements on all parts of the current conductor. The source can be located in the insulation of current conductor, in outgoing cable lines or couplings (including the transformer). According to the measurement results with a high degree of probability, partial discharge is located in the "C" phase.

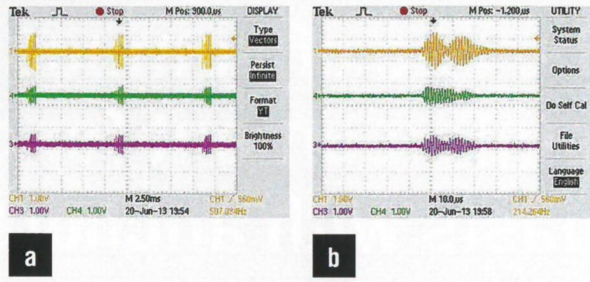

Fig.7 — Waveforms of partial discharge pulses registered by means of sensors (high-frequency transformers), at the moment of absence of arcing:
a) — on the sweep of 2.5 ms/div. (1 period of network frequency),
b) — on the sweep 10 μs/div.

To investigate the location of a partial discharge in the insulation of CRIB current conductors with a total length ~ 1.5 km using the electromagnetic non-contact or acoustic method, a high-frequency scanner (Fig. 3c, d) was used.

Since the customer is particularly concerned about the state of the couplings, which were filled in inclement weather (with all the protection methods according to the instructions), these areas were examined most carefully, including, with a climb to the current conductor and, in some cases, disassembly of the protective screens. Nevertheless, there was no discharge phenomena found in the insulation of conductors. Exploitation of these conductors over the next few years confirmed the correctness of findings of diagnostic survey.

SUMMARY AND CONCLUSIONS

The following is required to ensure operational reliability and safety at servicing conductors with cast insulation:

1. to measure the partial discharge during post-installation and periodic operational diagnostic control;
2. to include the specified requirement in the instruction manual of current conductors, and also to the new edition of the standard regulating the scope and norms of electrical equipment tests.

REFERENCES

1. GOST 15150-69 Machines, instruments and other industrial products. Modifications for different climatic regions. Categories, operating, storage and transportation conditions as to environment climatic aspects influence
2. CO 34.45-51.300-97 Scope and norms of testing of electrical equipment.

АВТОР

Dolin Anisim Petrovich was born in 1950. PhD in Technical Sciences, General Director of the Scientific and Technical Center "Electroengineering, Diagnostics and Service", Associate Professor of the Moscow Power Engineering Institute (Technical University). He is an expert in the field of electrical equipment diagnostics, calculation of current conductors of various designs and in overhead lines. He has published more than 150 publications for this subject, including monographs and textbooks. He is the author of 18 federal and industry standards for the electric power industry, including "The scope and standards of electrical equipment tests", "Standard program of complex diagnostic transformers investigations", etc.