TELEMETRIC MONITORING INSULATION CONDITION OF HIGH VOLTAGE OVERHEAD POWER LINES

Iosif Breido, Vladimir Kaverin & Valeriy Ivanov.

This Publication has to be referred as: Breido, I[osif]; Kaverin, V[ladimir] & Ivanov, V[aleriy] (2018). Telemetric Monitoring Insulation Condition of High Voltage Overhead Power Lines, Proceedings of the 29th DAAAM International Symposium, pp.0319-0328, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-20-4, ISSN 1726-9679, Vienna, Austria
DOI: 10.2507/29th.daaam.proceedings.046

Abstract

The conditions of operation and the causes of failures in the operation of high-voltage overhead transmission lines are considered. The review of existing methods of monitoring the state of external insulation has been carried out and a method for monitoring the insulation state of high-voltage insulators under operating voltage has been proposed by measuring the leakage current. The review of methods of information transmission over GSM networks is carried out, the analysis of various methods of increasing noise immunity and reliability of received telemetry signals is made. A current sensor has been developed that allows wireless allotment of insulator leakage current values and the use of GSM networks. Experimental studies of the quality of telemetric information transmission from the supports in GSM networks using GPRS technology have been carried out.

Key words: high-voltage insulators; control of the insulation state; leakage current of insulators; GSM networks

1. Introduction

Transportation of electricity from production sites to places of consumption is one of the important tasks of the energy sector. High-voltage overhead power lines (HVPL) are the most emergency element in the single technological chain of supplying consumers with electricity. More than half of all interruptions in power supply are caused by the problems of HVPL. The condition of insulation on transmission and distribution power lines is one of the most important conditions for the successful operation of the power system. Insulators that are damaged or do not meet the requirements for their electrical characteristics can lead to power supply interruptions.

Currently, non-destructive diagnostics is a trend in the construction of modern diagnostic systems. The main task of the insulation condition diagnostics is the conclusion about the possibility or impossibility of further safe operation of equipment. Reliability of HVPL directly depends on reliability of the external insulation, for which provision suspension insulators are used.

A significant part of HVPL outage causes are force majeure, and cannot be prevented by means of operational diagnostics. These are various unpredictable atmospheric influences, natural and geological features of the HVPL route, the influence of abnormal operating modes of the line. At the same time, not less than half of all outages can be transferred from the unpredictable category to the predictable one if monitoring systems are used to monitor their condition.

In the number of outages causes the first place is occupied by wires (52 % taking into account thunderstorm overvoltage and 37 % without taking them into account), the second place is occupied by insulators (31 and 23 %, respectively), in the third place there are supports (13 and 9 %), in the fourth place reinforcement (4 and 3 %) [1], [2], [3], [4], [5], [6], [7], [8].

About 60 % of all failures are due to insulation damage. The number of failures is growing and their growth is from 3 to 5 % per year. One of the main causes of reducing characteristics of linear insulation is contamination of its surface during operation. Contamination reduces electrical strength of insulation and in some cases causes a superficial overlap, thereby disrupting normal power supply [1], [2], [3], [4], [5].

The purpose of the study is to monitoring of the insulators condition with telemetric information transmission, which will allow to monitor the state of isolation of high-voltage insulators in real time under operating voltage during the operation of the line. To achieve this goal it is necessary:

- to consider the operating conditions and causes of failures in the operation of high-voltage insulation of overhead power lines;
- perform review of existing methods for control of insulation condition;
- determine the necessary parameters and develop a sensor for monitoring the insulation state;
- carry out experimental studies of the proposed sensor with telemetry information transmission using GSM-networks.

2. Theoretical analysis

The operation of insulators proceeds under the following conditions [1], [2], [3], [5], [9], [10]:

- continuous exposure to the voltage of the rated value, taking into account possible allowable overvoltage in the line;
- continuous contamination with particles suspended in the air as a result of natural and industrial air pollution;
- the impact of atmospheric precipitation and other atmospheric conditions.

To improve the quality of insulation it is required to increase the number of insulators in the garland. However, increasing the number of insulators in the garland leads to increasing economic costs and does not solve the problems of monitoring the state of insulation. With deterioration of the insulation of suspended insulators, the probability of overlapping insulation and occurrence of a short circuit to the ground increases dramatically, which also leads to increasing power losses in the HVPL [11], [12], [13], [14].

At this, in most cases the insulators themselves do not collapse and in the future restore their electrical strength, which indicates the overlapping of insulation rather than its breakdown, i.e. the cause of the failure is an incorrectly selected insulation level. It is also worth noting that not all cases of overlapping insulation are reflected in the annual reports on the household of electricity supply due to imperfections in the system of transmitting information of technical devices failures from power supply distances to the upper level of control.

Therefore, it is necessary to ensure the optimum reliability of insulation from the economic point of view. This task is solved by coordinating the isolation - establishing and maintaining in the process of operation the necessary coordination between the electrical strength of the insulation and the stresses acting on it.

Today there are many different methods of monitoring the state of insulation. All existing methods of controlling insulation can be divided into two groups [15], [16], [17], [18]:

- destructive;
- non-destructive.

Destructive methods require a lot of labor and do not provide a current monitoring of the insulation condition under operating voltage during operation. That is why the urgency and economically expedient improvement of the diagnostic system are justified, however, the existing diagnostic methods and the planned maintenance system do not provide required reliability and promptness of obtaining information of the HVPL sections having reduced electric strength of the external insulation. Improving the methods for diagnosing the surface electrical strength of insulating structures will allow transiting to the maintenance system according to the technical condition that is more reliable and cost-effective than the planned maintenance system [17], [18], [19], [20], [21].

Linear suspension insulators are usually characterized by a long service life and do not require much effort to maintain their normal technical condition. Nevertheless, it is useful to take preventive measures in order to identify damaged (degraded) or out-of-date insulators before they make serious problems.

Since the operational durability of specific insulators is difficult to predict, their state should be periodically monitored in order to constantly ensure proper line reliability [5], [10], [12], [13], [14], [19], [21], [22], [23]. One of the informative parameters that characterizes the quality of insulation is the leakage current [24], [25], [26], [27], [28], [29].

The evaluation of the state of the external insulation of the HVPL in terms of the leakage currents makes it possible to carry out the following [9], [10], [12], [14], [18], [19]:

- operational control of the electrical strength of insulation, which allows judging the potentially dangerous level of contamination and carrying out a set of measures aimed at the timely conducting appropriate preventive measures to bring the insulators electrical strength to the level corresponding to the operating conditions (cleaning insulation, washing under tension, etc.);
- identification of the areas in which reinforcement of insulation is necessary (increasing electrical strength by increasing the length of the insulating structures leakage path, replacing insulating structures, etc.);
- increasing reliability of the HVPL operation by improving control over the external insulation parameters (the number of the power line outages is reduced).

3. Methodology of experiments

A system for monitoring the leakage current of insulators with information telemetric transmission has been developed, which makes it possible to diagnose the insulation state of high-voltage insulators in real time under voltage. Its basis is the leakage current sensor, the results of experimental studies of which are given in [30], [31], [32], and Fig. 1 shows its structural diagram.

Fig. 1. Structural diagram of the leakage current sensor

The current sensor contains: measuring transformer T1, amplifier A1, interference suppressor filter A2 of low frequencies, precision rectifier A3, filter A4, integrator A5, analog-to-digital converter A6 and GSM / GPRS modem A7.

The circuit works as follows: the total leakage current of the insulators that consists of the volume component determining the state of the insulator dielectric and the surface component determining the value of the insulation contamination is measured with current transformer T1 containing the measuring W_P and compensating W_{OC} windings. Voltage from the measuring winding is amplified by amplifier A1, filtered by filter A2 from the high-frequency noise constituting the corona current and surface partial discharge currents and is supplied to the compensation winding of transformer T1. The current of this winding, with the help of resistor R1 is converted into AC voltage and converted into direct current voltage by precision rectifier A3, the output signal of which contains volumetric U_0 and surface U_n leakage current components that are then averaged and summed in time by filter A4 and integrators A5. Then this voltage is converted into the digital code in the ADC A6 and transmitted via the GSM / GPRS modem A7 to the control point where the leakage current is compared with its permissible value. Based on this, an assessment is made of the insulation state and the need to take measures to bring the insulation resistance up to normal operating values or to decide on the further possibility of operating insulators.

The leakage current sensor is mounted on the grounded end of the linear suspension or pin-and-pin insulator. It can be implemented as a part of the garland of insulators, when the phase conductor is isolated from the support by several insulators, and on a separate linear suspension insulator, when the phase wire is isolated from the support by one insulator.

This method allows continuous monitoring the degree of contamination of insulators or electrical strength of insulation magnitude at any desired point in the power line.

The cost of measuring leakage currents by this method is significantly reduced by eliminating the cost of massive cumbersome insulating structures, since the current sensor is not at a high potential of the line and has galvanic isolation.

To measure the leakage current, high voltage has been applied from the output of test transformer T2. Voltage regulation has been carried out on the low side of the test transformer by means of a single-phase laboratory autotransformer T1 with the voltage regulation limit from 0 to 250 V. The leakage current of the insulator has been measured by milliammeter PA2. To protect transformers from the flow of currents exceeding the rated values, current protection has been established on the basis of current relay K1 connected through current transformer TA1 to the secondary circuit of the autotransformer. When the current reaches the measuring circuit of the pickup threshold, the power supply of the bench is terminated. Spark gap F1 is designed to protect against exceeding the test voltage.

According to GOST 10390-86, the source of alternating voltage (test transformer together with the regulating device) should be selected so that the effective value of the short-circuit current is at least 10 times higher than the largest value of the amplitude of the leakage current pulses for the insulator under test not leading to the closure of the insulator.

According to the calculation results, the effective value of the short-circuit current for this installation is 0.5 A. Consequently, such an alternating voltage source makes it possible to carry out insulation tests with the amplitude of leakage current up to 50 mA. The leakage current sensor testing has been carried out on a laboratory bench, the diagram of which is shown in Fig. 2.

QF1 – automatic switcher, SB1 – button of leakage current measuring; T1 – single-phase automatic transformer, TA1 – current transformer; K1 – electromagnetic current relay; R1 – limiting resistor; T2 – testing transformer; OS – object to be studied (insulator); F1 – spark gap; A1 – leakage current sensor developed

Fig. 2. Diagram of a laboratory bench for testing the leakage current sensor

Telemetric transmission of information on leakage currents from the supports can be carried out based on the wireless GSM-networks.

There are three basic methods: via SMS short message service (ShortMessageService), GSM voice channel and using GPRS packet data (GeneralPacketRadioService) [33], [34], [35].

The data transmission via SMS messages is used for a small amount and number of information packages, for example, to send alarm messages about abnormal situations in applications that are not time-critical. The disadvantages of it should be, first of all, not guaranteed fast delivery of messages and a small number of characters in it: up to 160. These circumstances impose significant restrictions on the use of SMS in monitoring systems of process facilities in real time.

The data transmission over the CSD voice channel (CircuitSwitchedData) allows exchanging the data of any volume between two objects in real time (on-line) in the format of the point-to-point connection. The main advantages of this method of communication are higher reliability and data transmission speed. The maximum data transfer rate for one GSM voice channel (CSD mode) is 9600 Kbps. The disadvantages of using the GSM voice channel include a significant cost of sending kilobytes of information when transferring small amounts of data. For example, the transmission time of 20 Kbit of information makes approximately 2 seconds, and the session time can vary from 2 to 16 seconds, depending on the mode of operation of the modems. Since subscribers pay for this time, it is inefficient to use financial resources [33, 34, 35].

The main feature of the data transmission using packet data transmission GPRS is the ability to connect permanently a subscriber to the network. The radio channel is provided to a subscriber only for the time of transmission of the data packet, at the rest time it is used for transmission of packets of other users of the network. With this method of communication payment is only for traffic, and not for the entire duration of the communication session.

GPRS technology is optimal for application in the systems of continuous monitoring mobile and stationary objects. The maximum possible data rate with the help of GPRS technology can theoretically reach 170 Kbit / s [33], [34], [35]. In this project the data have been collected from the leakage current sensor of a modem connected by GSM via the RS-485 channel. Reception of the requested information is carried out by the head GSM modem with a static IP address. Generation of the request and data archiving is carried out by a SCADA-system deployed on the base of a personal computer.

To monitor the quality of the information transfer channel a converter and signal transmission diagram has been developed shown in Fig. 3. It consists of power supply A1, test signal module A2, module A4 for converting the analog signal to the code, and GSM/GPRS modem A5.

Fig. 3. Diagram of converting and transmitting a signal

Module A2 generates test signals. The values of the test signals 1V and 2V have been preset and are set by resistors R1 and R2, respectively. Then these signals are converted into a digital code and transmitted via GSM/GPRS modem to the control center, where the received signal is compared to the transmitted one, and in case of coincidence a relative estimate is given of the quality of the communication channel (100 %). If these signals do not match, then the channel quality is estimates as 0 %.

Since the processes of changing the insulation state are rather slow, the measuring interval of the leakage currents has been determined as 1 $\mu\text{m}/\text{h}$. The study has been carried out within 60 days with the selected transmission interval of the message $\text{TPRD} = 1$ message/hour. The analysis of the received data in conditions of real industrial interference from high-voltage equipment allowed estimating in relative units the quality of GSM communication in the conditions of an industrial enterprise.

4. Results and discussion

In the course of testing the use of GSM networks as a communication channel for transmitting telemetric information, the following results have been obtained. Fig. 4 shows the daily channel quality schedule within 2 months.

Fig. 4. Communication daily schedule

To analyze the communication quality within a day there has been considered an arbitrary day. Fig. 5 shows an hourly schedule of the communication quality.

Fig. 5. Communication hourly schedule

It can be seen in the schedules that under the conditions of intense electromagnetic interference the quality of the GSM channel is approximately 50 %, and additional measures should be taken to increase reliability of message transmission. One way to increase reliability of transmission is using feedback to construct a transmission system [37], [38], [39], [40]. The structural diagram of the system with information feedback (IF) is shown in Fig. 6.

Fig. 6. Structural diagram of a system with information feedback

If the message (IS) from the control (monitoring) point (CP) is transmitted in the form of an unprotected code, in the encoder this code can be converted into an anti-jamming code. However, since this is usually not necessary, the CD (2) encoder is a register for converting a simple parallel code to a serial code. Simultaneously with transmission in the direct channel (DCH) the message is stored in the drive M (3) in the CP. At the dispatcher point (DP) the received message is decoded in the DC decoder (5) and also stored in the storage device (6). However, the message is not sent immediately to the recipient: first it is sent through the reverse channel (RCH) to the control (monitoring) point. In diagram 4 a comparison is made between the received message and the transmitted message.

If the messages are the same, an acknowledgement signal (AS) is generated that the previous message has been received correctly and the information can be transferred from the drive to the recipient (IR) and subsequent messages are transmitted.

If the messages do not match, which indicates an error, an erase signal (ES) is generated. This signal locks key 1 to stop transmission of the next message and is sent to the DP to destroy the message recorded in drive 6. After this, the transmission of the message recorded in information storage (3) is carried out from the control point.

In systems with IF, the leading role belongs to the transmitting part, since it determines the presence of an error, the receiver only informs the transmitter what message has been received.

Various transmission options with IF are possible. Thus, an option is possible, in which signal transmission occurs continuously and stops when an error is detected: in this case the transmitter sends an erase signal and repeats transmission [37], [38], [39], [40].

This type of communication requires organization of a two-way (direct and reverse) channel, which leads to a significant complication and cost of the equipment and leads to increasing the transmission time of messages.

An option is possible in which not the entire information is transmitted through feedback, but only some characteristic information of it (receipts). For example, in the direct channel there are transmitted the information, and in the reverse channel the pilot symbols that the transmitter will be compared with the preset pilot symbols [37], [38], [39], [40].

There is a variant in which, after checking the received message in the reverse channel and error detection, the transmitter can either repeat it (duplication of messages), or send additional information required for correction (correction information). The number of repetitions can be limited or unlimited. The reverse channel is used to determine whether retransmission of information is necessary [37], [38], [39], [40].

One more way to increase noise immunity is transmission of information with repetition (accumulation) [37], [38], [39], [40].

This method of transmission is used to increase reliability in the absence of the reverse channel, although there are no fundamental limitations for its use and feedback. Sometimes such a method is classified as the reception of messages by accumulation. The essence of the method consists in sending the same message a few times, remembering received messages, comparing them element-by-element and composing a message including the elements chosen "by the majority".

Let's suppose that the same code combination 1010101 is transmitted three times. In all three transmissions it has been subjected to interference and distorted:

- 1) 1 0 0 0 1 0 0
- 2) 1 1 1 1 1 0 1
- 3) 1 0 1 0 0 0 1
1 0 1 0 1 0 1

The receiver bitwise compares the three received symbols and places those symbols (below the line), the number of which in the given category prevails.

There is another method of transferring information with accumulation, in which not a symbol-by-symbol comparison is produced, but a comparison of the entire combination as a whole. This method is easier to implement, but it provides worse results [37], [38], [39], [40].

Thus, high noise immunity of the method of information transmission by spontaneous accumulation is based on the fact that the signal and interference in the channel do not depend on each other and vary according to different laws (the signal is periodic and the interference is random), so the repeating combination in each transmission will be, as a rule, distorted in different ways.

As a consequence, at reception the accumulation, that is summation of the signal, increases in proportion to the number of repetitions, while the sum of the interference increases according to another law. If we assume that the interference and the signal are independent, then the mean squares are summed and the mean square of the sum increases in proportion to the first power. Therefore, in n repetitions, the signal-to-noise ratio increases by the n factor, and this happens without increasing the signal power. However, the equipment becomes more complex and the transmission time increases.

In systems with IF increasing reliability of the transmission is achieved by repeating the information only in the presence of an error, whereas in systems without feedback (during transmission with accumulation), the repetition is carried out regardless of the message distortion. Therefore, in systems with IF information redundancy is much less than in systems with no feedback: it is minimal in the absence of distortion and increases with errors. In systems with IF the quality of the reverse channel must be no worse than the quality of the direct channel in order to avoid distortions that can increase the number of repetitions [37], [38], [39], [40].

Proceeding from the analysis of specificity of changes in the parameters of the external insulation of the HVPL showing that the processes of deterioration of insulation are rather slow, the interrogation of its state occurs at intervals per hour, and because the introduction of feedback would lead to a significant complication and increase in cost of equipment, it is rational to use simpler methods of information transfer (the method of repetition or accumulation). This is confirmed by the results of testing this transmission method that ensures high reliability.

Messages have been transmitted at intervals of 1msg/h and repeated 5 times with a slight delay. If at least three of the received messages have been with the same information, then this message has been accepted as reliable. In total for the period of carrying out experimental research from 14/05/2017 to 02/10/2017 there have been transmitted 3341 messages, of them 34 messages have been received with errors. Fig. 7 shows the number of distorted messages within the period under test.

Fig. 7. Number of messages with errors within the period of testing

This, as a result of the testing the percent of distorted messages has made:

$$N_{ERR} = \frac{n_{ERR}}{n_{\Sigma}} = \frac{34}{3341} \cdot 100 = 1,01\%$$

This confirms that using the method of repetition (accumulation) is rational and provides high reliability of message transmitting when using GSM-networks as the transmission channel.

5. Conclusions

The conditions of operation and the causes of failures in the operation of high-voltage overhead power lines are considered. The review of existing methods of monitoring the state of external insulation has been carried out and a method for monitoring the insulation state of high-voltage insulators under operating voltage has been proposed by measuring the leakage current.

A current sensor has been developed that allows wireless allotment of insulator leakage current values and the use of GSM networks. The analysis of methods of telemetric transmission of leakage currents from supports has been carried out, and the option of using GPRS technology has been proposed.

During the tests it has been found out that under conditions of intense electromagnetic interference, the quality of the GSM channel is approximately 50 %, and additional measures should be taken to increase reliability of message transmission. The analysis of various methods of increasing noise immunity and reliability of received telemetric signals has been carried out.

Taking into account specific features of the processes of changing the leakage currents during the operation of a high-voltage power line, the accumulation method has been used to increase noise immunity of the transmission system. Each message has been transmitted 5 times with a slight delay. If at least three of the received messages have been with the same information, then this message has been accepted as reliable. Experimental studies of the developed sensor have been carried out for 5 months. The share of distorted messages was 1.01 %, which confirmed a high efficiency of the developed telemetric system for monitoring the leakage current of HVPL high-voltage insulators.

Thus, the use of GSM-networks as a channel for transferring technological information allows using the proposed leakage current sensor to construct a monitoring system for the insulation state of high-voltage power lines under operating voltage in real time.

The proposed technical solutions make it possible to use them further for continuous monitoring of the high-voltage insulators condition, which will ensure current monitoring of the insulation condition and prediction of its resource for taking timely measures to bring it to a normal state or decisions about possible further operation.[41]

6. References

- [1] Kaverina R., Kogan F. & Yakovlev L. (2007). Improving reliability of overhead lines 35-750 kv. A complex of works and proposals. Colourful magazine «The News of Electrical Engineering» No. 5 (47).
- [2] Yakovlev, L.V., Kaverina, R.S. & Dubinich L.A. (2008). Complex of works and proposals for increasing reliability of overhead lines at the stage of design and operation. Power transmission lines: design, construction, operating experience and scientific and technical progress., ISBN 978-5-93889-144-9, Novosibirsk, p. 28-50.
- [3] Kashevarov, S.G. (2015). Damages of power transmission lines and review of new technical and organizational solutions for their limitation. Current state and prospects for the development of technical sciences: Collection of articles of the International Scientific and Practical Conference (May 23, 2015. Ufa), ISBN: 978-5-906781-48-2, Ufa: RIO MZ Omega Sainz, p. 58-63.
- [4] Kogan, F.L. (2008). Complex of works and proposals for increasing reliability of overhead lines at the stage of their design / F. L Kogan, R.S. Kaverina // Branch "Firm ORGRES". Materials of the conference of the CIS Electric Power Council.
- [5] Merkhalev, S.D. & Solomonik, E.A. (1983). Selection and operation of insulation in areas with the contaminated atmosphere. L.: Energoatomizdat, 120 p.
- [6] Thionc, L. (1994). Dielectric strength of external insulation systems under live working. Proc. 35th CIGRE Session, Paris, p. 33-306.
- [7] Manone, G. et al. (1994). Investigation on the dielectric strength of damaged insulation strings of HV overhead lines during repair operations by live working. Proc. 35th CIGRE Session. Paris, p. 33-305.
- [8] Hutzler, B. (1988). Strength of external insulation during live line maintenance and repair work with special reference to transient overvoltage // Proc. 32th SIGRE Session, Paris, p. 33-307.
- [9] Komolov, A.A., Korkina, S.V. & Rutski, V.M. (2010). Problems of exploitation of high-voltage insulation in a polluted atmosphere. Bull. of Samara research center of the RAS. No. 1. P. 482-484. . ISSN 1990-5378
- [10] Gul, V.I., Nizhevsky, V.I., Khomenko, I.V., et al. (2009). Coordination of insulation and overvoltage in electrical high-voltage networks: tutorial. Ed. prof. Gul V.I., ISBN 978-966-8230-48-6, Kharkov: EDENA, 270 p.
- [11] Zhelezko, Yu.S., Artemiev, A.V. & Savchenko, O.V. (2004). Calculation, analysis and normalization of electric power losses in electric networks: guidelines for practical calculations, ISBN 5-93196-264-6, M.: NTS ENAS, 280 p.
- [12] Regulations of the expert system for monitoring and assessing the condition and operation of overhead power lines 110kV and above (2000). RD 153-34.3-20.524-00. M.: RAO "UES of Russia", 14 p.
- [13] Guidelines for selecting insulation of electrical installations (1990). RD 34.51.101-90. M.: SPO Soyuztekhenenergo, 46 p.
- [14] Standard guidelines for operation of overhead transmission lines voltage 35-800 kV (1991). RD 34.20.504 – 94, M.: SPO ORGRES. Part 1, 108 p.
- [15] Thionc, L. (2000). An overview of line diagnostic techniques // Proc. 38th CIGRE Session, Paris, p. PI-02.
- [16] Arbuzov, R.S. & Ovsyannikov, A.G. (2004). Methods of diagnosing glass and polymer insulation. Power transmission lines-2004: Operational experience and scientific-technical progress. Coll. of reports at the 1st Intern. scientific-practical. Conf. Ed. I.T. Chernova. ISBN 5-93889-031-5, Novosibirsk, p. 57-65.
- [17] Arbuzov, R.S. (2009). Modern methods of diagnosing overhead transmission lines / R.S. Arbuzov, Ovsyannikov A.G., ISBN 978-5-02-023275-4, Novosibirsk: Nauka, 136 p.
- [18] Vinogradov, A.V., Kashevarov, S.G. & Pavelko, N.Yu. (2015). Problems, tasks and solutions for monitoring the state of electric grid equipment. International Scientific Journal "Innovative Science". No. 7. V. 1. P. 16 -20., ISSN: 2410-6070.
- [19] Methodical guidelines for controlling electrical equipment under the operating voltage (1996). RAO "UES of Russia". M., 16 p.
- [20] Svi, P.M. (1992). Methods and means of diagnostics of high voltage equipment., ISBN 5-283-01062-7, M.: Energoatomizdat, 240 p.
- [21] Svi, P.M. (1988). Insulation monitoring of high voltage equipment: 2nd ed., rev. and add., ISBN 5-283-00995-5, M.: Energoatomizdat, 126 p.
- [22] Cimador, A. Reliability of insulators for overhead lines / Lapeyre J. L., Parraud R., De Toureil C.// 35 -th CIGRE Session. – Paris., 1994. –Panel 3 – 04.
- [23] Johannet, P. (1995). The behavior of external insulation in an overhead system. LAB Echo. No. 3, p. 3.
- [24] Komolov, A.A. (2011). On the possibility of applying information on the leakage current through the surface of contaminated and moistened insulation for the purpose of diagnosing its electrical strength./ A.A. Komolov, V.M. Rutskiy// Bulletin of Transport of the Volga Region. No. 2, p. 60-65., ISSN 1997-0722

- [25] Komolov, A.A. (2013). Improvement of methods for monitoring the technical condition of external insulation of the traction power supply system by leakage current: diss. Cand. Tech. Sci.: 05.14.12, VVK O217.22-082.705.1,0, Samara, 189 p.
- [26] Engineering of high stresses. Textbook for students of electrical and power engineering specialties of higher education institutions (1976) / Gen. ed. D.V. Razewig. 2nd ed., rev. and add. M.: Energy.
- [27] Bazutkin, V.V. (1986). High Voltage Techniques: Isolation and Overvoltage in Power Systems: A Textbook for Universities; 3rd ed., rev. and add. M.: Energoatomizdat, 464 p.
- [28] Voskresenskiy, V.F. (1971). Electrical isolation in areas with a polluted atmosphere. M.: Energia, 80 p.
- [29] Kuffel, E., Tsaengl, V. & Kuffel J. (2011). Technique and electrophysics of high stresses. Trans. from English: Educational reference book., ISBN: 978-5-91559-053-2, Dolgoprudny: Publishing House "Intellect", 520 p.
- [30] Ivanov, V.A., Breido, I.V., Kaverin, V.V. & Em, G.A. (2016). Development and experimental research of the leakage current sensor for high-voltage insulators. University Proceedings, ISSN 1609-1825, Karaganda: KSTU, No. 3
- [31] Ivanov, V.A. (2016). Diagnostics of insulation of high-voltage insulators in terms of leakage current value./ V.A. Ivanov, V.V. Kaverin// Proceedings of the International Scientific and Practical Conference "Integration of Science, Education and Production as the Basis for Realizing the Plan of the Nation" (Saginov's Readings No. 8). June 24, 2016. Part 4., ISBN 978-601-296-054-9, Karaganda: KSTU Publishing House.
- [32] Ivanov, V.A., Breido, I.V., Kaverin, V.V. & Em G.A. (2016). The detector of leakage currents of high-voltage insulators. VI International Scientific and Technical Internet Conference of Young Scientists "Automation, mechatronics, information technologies". May 17, 2016, Omsk, ISBN: 978-5-8149-2290-8, Omsk State Technical Universitet.
- [33] Dianov, I.V. (2009). M2M: Use of GSM-networks for data transmission in geographically distributed technological systems. Vestnik Svyazi. No.10, p.14-18., ISSN 03208141.
- [34] Lipovets, A. (2006). Using the GSM network and ISaGRAF technology to build a data collection system. Wireless Technologies. No. 1, p. 51 – 52, ISSN 2079-9233.
- [35] Maslenkov, I. & Komantsev, A. (2008). GSM/GPRS technologies in industrial automation systems. Control Engineering Russia. November-December, p. 2-6., ISSN 18817-0455.
- [36] Moiseyenko, D. (2003). Optimization of the operation of modems WAVECOM in the mode of data transmission via GSM network. Components and Technologies. No. 4., ISSN 2079-6811.
- [37] Tutevich, V.N. (1985). Telemechanics: tutorial for university students of spec. "Automation and telemechanics." 2nd ed., rev. and add. M.: Higher School, 423 p.
- [38] Penin, P.I. (1976). Transmission systems for digital information. M.: Sov. Radio, 368 p.
- [39] Kuzmin, I.V. & Kedrus, V.A. (1986). Fundamentals of information theory and coding. 2nd ed., rev. and add. K.: Vishcha shkola, 238 p.
- [40] Shuvalov, V.P., et al. (1990). Transmission of discrete messages: Textbook for higher schools, . ISBN: 5-256-00852-8, M.: Radio and Communication, 464 p.
- [41] Ivanov V., Breido I., Kaverin V., Levin I. Voytkevich S. (2017) System of protection and diagnostics of structural elements of support of high-voltage power lines. In Annals of DAAAM for 2017& Proceedings of 28th International DAAAM Symposium. Vienna: DAAAM International, ISBN 978-3-901509-73-5. ISSN 1726-9679, Katalinic, B. (Ed.), pp. 1-9, Published by DAAAM International, Vienna, Austria, EU