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# METROLOGICAL ESTIMATION OF MEASUREMENT ERROR WITH THE DETERMINATION OF THE TECHNICAL STATE OF SUBSTATION ELECTRICAL EQUIPMENT

**Alexander Yu. Khrennikov[1†] --- Roman V. Mazhurin[2] --- Pavel S. Radin[3]--- Tanya A. Khrennikova[4]**

[1]*Division of electrical equipment and transmission lines, Scientific and Technical Center of Federal Grid Company of United Energy System*

[2]*Southen branch of JSC "Federal Grid Company of Unified Energy System*

[3]*Far East Branch of JSC "Federal Grid Company of the Unified Energy System*

[4]*Moscow Energy Institute (Scientific Research University)*

## ABSTRACT

*This paper presents an application's experience of estimation of the technical condition state of electrical equipment. Federal Grid Company of United Energy System is the biggest Russian Company for the electrical energy transport. The diagnostics of the basic oil-filled equipment of substations is a very complex problem for the personal of electrical networks and stations .At present there are more than 20-30 electrical and other parameters, which must be measured for the inspection of the state of the electrical equipment. Quality and the authenticity of the results of diagnostic measurements are the guarantee of the trouble-free operation of electrical equipment, the absence of damage from the interruptions of the power supply of the users of electric power. Basic errors, which appear with the measurements of the diagnostic parameters of electrical equipment, are the instrument, systematic and subjective of errors. The errors enumerated above can be considerably decreased with the use of information tools, i.e., software and of specialized automated working place (further SAWP).*



**Keywords:** Maintenance and repair, Repairs "to on-state", Error of measurement, The automated working place, The estimation of technical state, Information tools, Specialized automated working place.

† Corresponding author
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**Contribution/ Originality**

This study uses new estimation methodology in the electrical parameter measurements.

## 1. INTRODUCTION

The electrical objects of Federal Grid Company of United Energy System (FGC Company) are located in 73 regions of the Russian Federation by the total area of more than 13,6 millions of square km. Company exploits 125,3 thousand km of overhead transmission lines ensures the functioning of 856 electrical substations with the total installed transformer capacity of more than 322,6 thousand MVA and the voltage from 35 to 1150 kV. In the company more than 23 thousand colleagues work.

Distributive Holding MRSK exploits 2100 thousand km of overhead transmission lines ensures the functioning of 451 000 substations with the total installed transformer capacity of more than 371 thousand MVA and the voltage from 6 to 220 kV. In the company more than 249 thousand colleagues work.

FGC Company, which is been the leader of the construction of new power engineering and introduction of the technologies “intellectual electric power network” (Smart Grid) in Russia, in 2011 proclaimed the concept of the construction of intellectual electric power system with the active- adaptive network. Intellectual electric power system with the active- adaptive network (IEPS AAN) is the electric power system of new generation, based on the multiagentnom principle of organization and control of its functioning and development for the purpose of the guarantee of effective use of all resources (natural, social and productive and human). For the understanding, the systems, which contain the group of the agents, which can interact between themselves and are called multiagentnom systems (Khrennikov, 1994).

With the passage to the system of the repairs of electrical equipment “to on-state” and the introduction of the system of planning the resources of enterprise FGC Company planning measures for maintenance and repair () of electrical equipment rose to qualitatively different level and, as consequence increased the requirements, presented to the estimation of equipment state (Fogelberg and Girgis, 1994).

The component part of IEPS AAN is the business- process “diagnostics of electrical equipment”, which is achieved within the framework the activity of FGC Company and is one of the most important business- processes. This occurs because the quality of the estimation of technical condition state (TCS) directly influences the reliability of the work of electrical equipment, the effectiveness of the functioning of company, and, as a result, to the investment FGC Company (McNutt *et al.*, 1970; Balakrishnan, 1989; Fogelberg and Girgis, 1994; Khrennikov, 1994; Khrennikov, 2000).

In entire TCS it allows objective and sufficiently complete information about the state of the active memberships of company, and by other ways, passing TCS, cannot be obtained this information. To make decisions and to evaluate controlling influences in the Company possible being only based on TCS (McNutt *et al.*, 1970; Malewski and Khrennikov, 1995; Khrennikov, 1999; Khrennikov, 2005; Khrennikov *et al.*, 2010; Khrennikov and Skladchikov, 2014).

## 2. TECHNICAL CONDITION STATE OF THE TRANSFORMER-REACTOR OIL-FILLED EQUIPMENT

TCS and the technical diagnosis of electrical equipment is divided into two basic segments: the diagnosis of the basic oil-filled equipment of substations and the diagnosis of the elements of air electrical lines. In Fig. 1 is given the classification of reasons and forms of damages, and also the schematic of the technical diagnosis of the transformer- reactor oil-filled equipment.

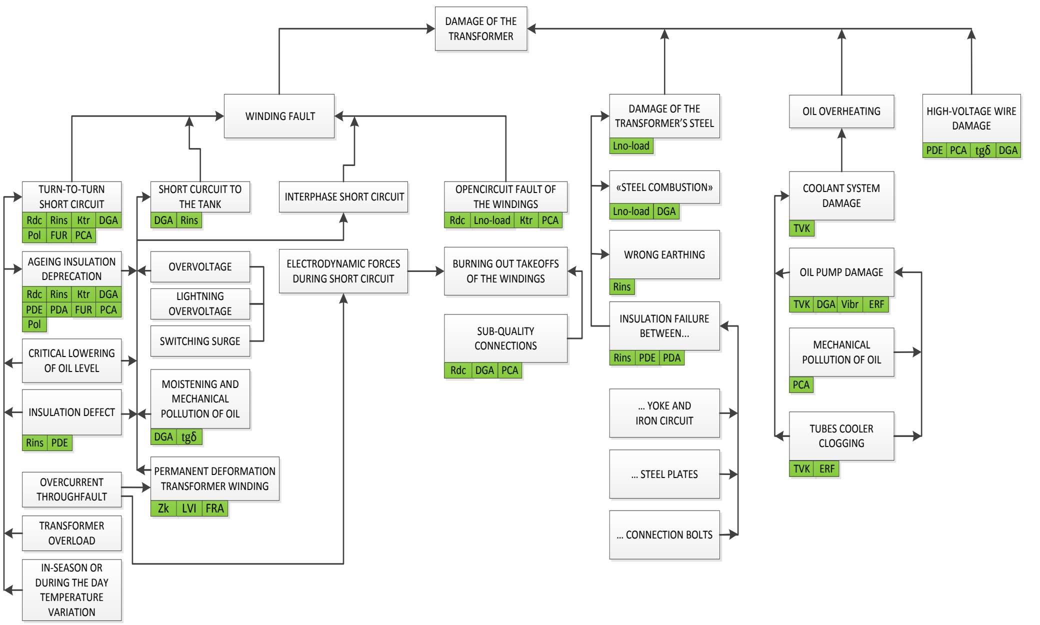


**Fig- 1.** The classification diagram of damage's reasons and forms. Schematic of the technical diagnosis of the transformer- reactor oil-filled equipment

Designations in the diagram: DGA - the chromatographic analysis of the dissolved gases of transformer oil, PCA - the physical chemistry analysis of transformer oil, Ktr - transformation ratio, Pol - the estimation of the degree of polymerization of paper insulation, Rins - the measurement of the insulation resistance, RDC- the measurement of direct-current resistance, FUR - the determination of the content of furan derivatives, tgδ - the determination of the dielectric power factor, PDA - level measurement of partial discharges by acoustic method, PDE - level measurement of partial of discharges by electrical method, LVI - diagnosis by the method of low-voltage pulses (deformation of windings), FRA - the determination of the mechanical state (deformations of windings) of transformer (reactor) by frequency response analysis, Zk - the determination of short-circuit impedance, Lno-load - the determination of the no-load losses, TVK - thermal-vision control, Vibr - measurement of vibration characteristics, ERF -estimates of the rate of oil flow (Lech and Tyminski, 1966; McNutt *et al.*, 1970; Balakrishnan, 1989; Malewski and Khrennikov, 1995; Khrennikov, 1999; Khrennikov, 2000).

 

On a quantity and the variety the methods of the diagnosis of the oil-filled equipment several times exceed the volume of the methods of diagnosis of overhead transmission lines, this is caused historically by closer attention to the reliability of the oil-filled equipment; by the same is caused the presence of a large quantity of finished effective systems "on-line" monitoring of the transformer equipment, for example, of such as control systems of bushings of R-1500, system of the checking of the transformer oil Hydran, TRANSFIX, TIM, TDM.

The guarantee of failure-free operation of electrical stations and networks of Russia, under the conditions of aging of electrotechnical equipment, and also the improvements of TCS system, optimization of expenditures for modernization and technical reequipping of the objects of power engineering requires both the creation of the new methods of diagnosis and improvement of the already used means of the inspection of the flaw detection of transformer and reactor electrical equipment (TREE) (Lech and Tyminski, 1966; Balakrishnan, 1989). Development and introduction of the new methods of diagnosis makes it possible to calculate the value of the worn resource taking into account of actual conditions and regimes of operation TREE (Lech and Tyminski, 1966).

The application of contemporary methods of diagnostics is directed toward the timely detection of the appearing defects, the adoption of measures for their elimination, the detection of the most worn units TREE and the determination of the priority of the modernization of power facilities. The development of the methods of diagnosis, especially used during the TREE service, will make it possible to switch over from the system of regular overhauls to repair system due to the technical state (TS) (Lech and Tyminski, 1966; McNutt *et al.*, 1970).

## 3. ESTIMATION OF ERROR IN THE ELECTRICAL PARAMETER MEASUREMENTS

The general percentage of errors in those influencing the quality of the estimation of the technical condition state of electrical equipment is given in Fig. 2 (Khrennikov and Goldshtein, 2007; Khrennikov, 2009; Khrennikov *et al.*, 2010).

**The instrument error** - this is the error, which is determined by errors in the means of measurements used, and it is caused by the imperfection of operating principle, by an inaccuracy in the calibration of the scale, by the lack of clarity of instrument - at present in practice excluded by means of the application of reliable and sufficiently precise means of measurements.

**The systematic errors** depend on the reasons, which act by the well-defined means. An example of a systematic error with the weighing can be the displacement of the pointer of unloaded balances relative to zero mark to a certain constant quantity $\Delta m$. Knowing this displacement (for example, after weighing the weight, whose mass it is accurately known), it is possible, every time measuring the mass on these weights, to deduct $\Delta$m from readings of instrument. Thus, systematic errors can be removed or sufficiently accurately taken into account.

**Subjective errors** - this of the errors, caused by the degree of attentiveness, concentration, preparedness and by other qualities of operator - in the recent decades it is not practically accepted effective measures for reduction in the data of errors; on the contrary, an increase in the influence of data of errors under the action of the following factors occurred:

- a notable increase in the quantity of equipment for that being undergoing TCS;
- a notable increase in the parameters of control TCS;
- an increase in the tempo of the fulfillment of works;
- an increase in information traffic of that processed by operator;
- an increase in the psychological load of operator (Khrennikov and Goldshtein, 2007; Khrennikov, 2009; Khrennikov *et al.*, 2010).

By subjective error in this paper is understood the influence of the errors, which appear, beginning from the stage, when the operator is readout the readings of instrument to the stage of the formation of conclusion about the state of object. The utilized methods and tools with working of the values, obtained with the direct measurements on the equipment, practically did not change (they were not improved) in the last 20 years (McNutt *et al.*, 1970; Khrennikov, 2005; Khrennikov and Goldshtein, 2007; Khrennikov, 2009; Khrennikov *et al.*, 2010; Khrennikov and Skladchikov, 2014).

If we accept the percentage of errors with TCS at the beginning of the 90's for the starting point, then at present the percentage of errors with TCS electrical equipment will be analogous with the given percentage in Fig. 2 (McNutt *et al.*, 1970; Malewski and Khrennikov, 1995; Khrennikov, 1999; Khrennikov, 2004; Khrennikov, 2006).

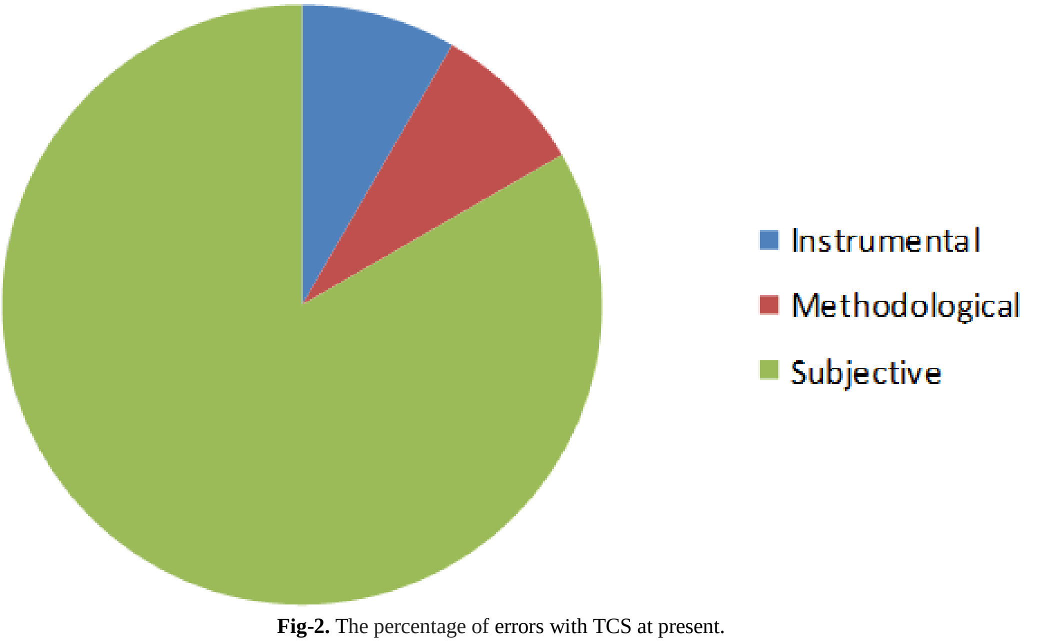


**Fig-2.** The percentage of errors with TCS at present.

In the different subdivisions the Company the percentage of subjective errors to the instrument and by systematic are different, but general tendency corresponds to that given in Fig. 2. Being based on this it is possible to draw the conclusion that after removing the reasons for the appearance of subjective errors (further errors) it is possible to considerably increase quality TCS.

Let us examine in what stages TCS and what factors lead to the appearance of error (Fig. 3).

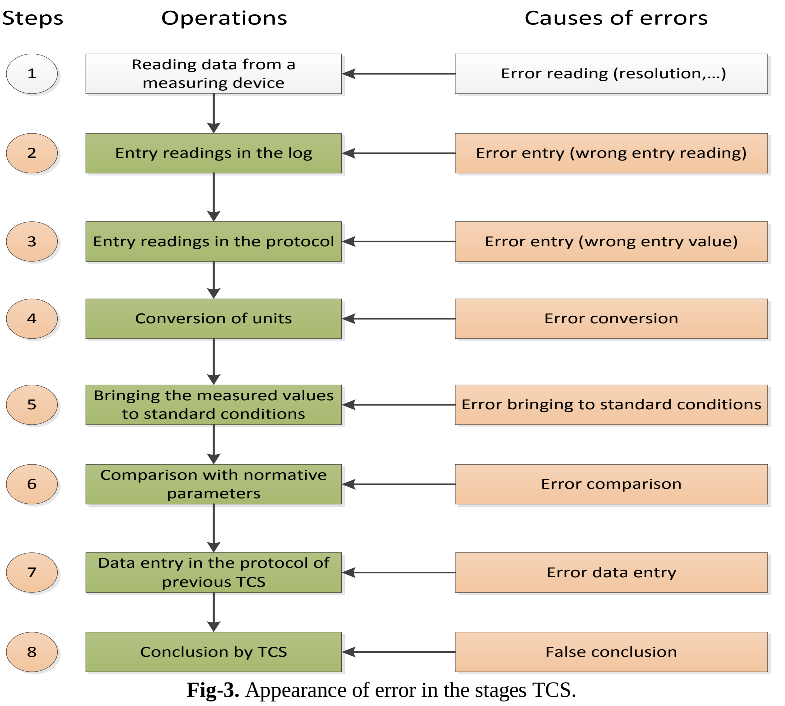


**Fig-3.** Appearance of error in the stages TCS.

Factors, indicated in Fig. 3 are specified on following basic reasons (Khrennikov and Goldshtein, 2007; Khrennikov *et al.*, 2010; Khrennikov and Skladchikov, 2014):

- the repeated transfer of data of one data carrier in another, what leads to entering of incorrect values - stage 2-7;

- "manual" calculation of values - stages 4,5; so bringing a number of the parameters of those utilized with TCS to the standard conditions is conducted with the aid of the nomograms (visual method), which so entering additional error;

- the absence of the reliable system of the verification both of the entered, calculated, corrected values and conclusion TCS - stages 1-8.

To remove the reasons, which cause error in stages 2-8, possibly, and this will be shown below. Concerning the first stage it is possible to say that with the standard measurements and the assumption about final attentiveness of operator the today this error is practically unavoidable (exception - control of counted data by the second operator) (Malewski and Khrennikov, 1995; Khrennikov, 1999; Khrennikov, 2000; Khrennikov, 2005; Khrennikov and Goldshtein, 2007; Khrennikov *et al.*, 2010; Khrennikov and Skladchikov, 2014).

## 4. RESULTS & DISCUSSION

To considerably descend, or more precisely to in practice exclude error is possible with the use of information tools. By information tool in this work is implied software, located on stationary computer, or on laptop. As a whole by information tool it is possible to understand the specialized automated working place (further SAWP) (Fig. 4).

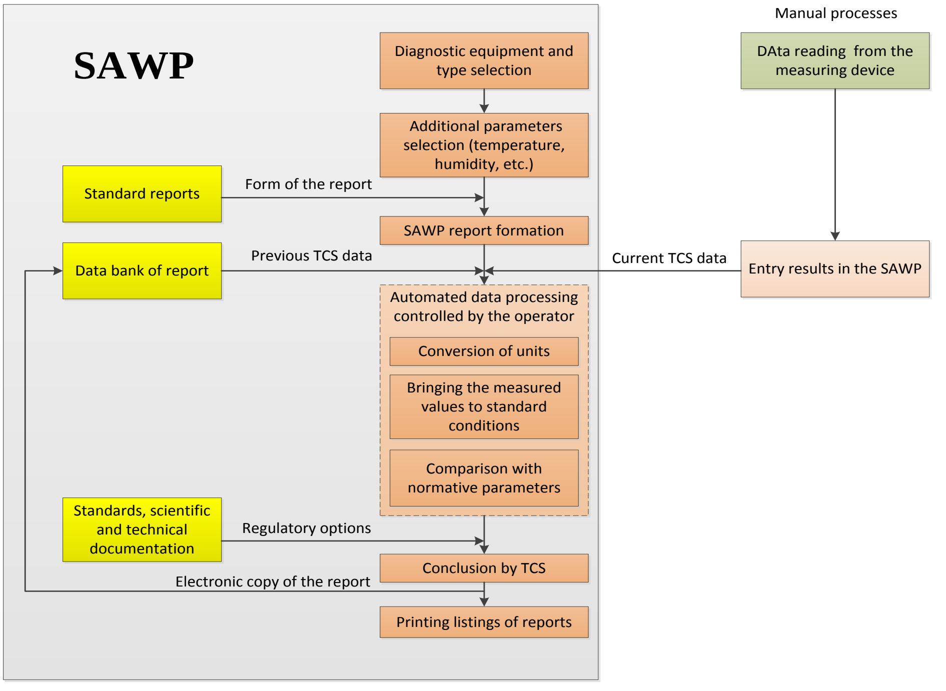


**Fig-4.** Block diagram of functioning SAWP.

The principle of use SAWP is extremely simple and consist only in the initial introduction by the operator of data of those obtained in stage 1 (Fig. 3), further transport and data processing is for the most part achieved by program; the function of operator - expert, in responsibility of whom enters only the administration of SAWP (Fig. 4). Since the errors, which appear in stages 2-8, are caused only by the subjective factor (emotional and mental condition of operator), with the exception of the direct influence of the state of operator on the process of decision making are excluded data of error, that leads to a substantial increase in the quality TCS.

With the use SAWP with TCS on stationary computer (they are established on all substations 220-750 kV JSC “FGC UES”) are excluded errors in stages 3-8 (Fig. 3). The probability of the occurrence of error in stage 2 remains and is caused by the need for the transfer in SAWP of data of the measurements, fixed in the periodical on the spot of the installation of equipment. With the use of laptop the periodical (Fig. 3, stage 2) is excluded and data are introduced by operator directly in SAWP, that makes it possible to exclude the probability of the appearance of an error by the caused specific character of stage 2 (Fig. 3) (Lech and Tyminski, 1966; McNutt *et al.*, 1970; Malewski and Khrennikov, 1995; Khrennikov, 1999; Khrennikov, 2000; Khrennikov, 2005).

At the present moment on the Russian domestic market for specialized software for diagnostics of electrical equipment:

- “Albatross”;

- “Information system of TCS diagnostics”. Papers (Khrennikov, 2012; Khrennikov, 2012; Khrennikov, 2013) in sufficient detail examine the merits of data of software. The most successful realization of program set acknowledged the expert- diagnostic system (EDS) “Albatross”.

It is possible to isolate the following basic merits of EDS “Albatross”:

- effective algorithms of TCS;

- the distributed system of TCS (level substation – district electric network- region electric network);

- the studied role mechanism.

At the same time in our view EDS “Albatross” it possesses the number of the deficiencies, which will not make it possible to use it in our Company without the significant modification. One of the conceptual deficiencies in the module EDS “Albatross” of substation level is its negative ergonomics and unjustifiably high complexity of the data input operator, that in our view not only are not decreased the subjective errors, but vice versa increases there, in spite of sufficiently effective internal algorithms of TCS of EDS “Albatross”.

At present on the basis the practical operating times of Far East Branch and theoretical studies of the Far-Eastern State University of communications are undertaken attempts at the development SAWP for the diagnostic subdivisions of those occupying TCS (Bertagnolli, 1998; Khrennikov, 2000; Khrennikov, 2004; Khrennikov, 2005; Khrennikov, 2006; Khrennikov and Goldshtein, 2007; Khrennikov *et al.*, 2010; Khrennikov, 2012; Khrennikov, 2012; Khrennikov and Skladchikov, 2014).

Basic condition of developed SAWP:

- progressive ergonomic interface - for the purpose of solution of basic problem - reduction in the load on operator and as the consequence of the decrease of the probability of the occurrence of subjective errors with TCS;

- simplicity of the utilized algorithms of TCS - in the stage of the formation of conclusion about equipment state according to the results of tests and measurements not rationally to begin to operate bulky prognostic algorithms;

- modular structure SAWP - for increasing the flexibility of system during its further modernization;

- the distributed structure of SAWP - with the use of an WEB- interface, for guaranteeing the condition of the access into the system from any computer of Company.

As a whole it is possible to make the preliminary conclusion that the use of special information tools (software) will make it possible to considerably decrease the subjective errors, which appear in the process of TCS of electrical equipment. Making a decision about development and introduction in JSC FGC UES of the tools of similar SAWP is extremely necessary, since TCS has a significant effect on the total effectiveness of Company.

Further stage of an increase in the effectiveness in the business- process “Diagnostics of electrical equipment” will be inclusion SAWP for TCS of electrical equipment in the composition of the expert- diagnostic system (EDS) of Company (Bertagnolli, 1998; Khrennikov, 2000;

Khrennikov, 2005; Khrennikov, 2012; Khrennikov, 2012; Khrennikov, 2013; Khrennikov *et al.*, 2013; Khrennikov, 2014; Khrennikov and Skladchikov, 2014; Khrennikov and Mazhurin, 2014a).

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AUTHOR BIODATE

**Alexander Yu. Khrennikov** was born in Bratsk, Russia, in 1964. He received Philosophy Doctor Degree in Electrical Engineering from Samara City University of Technology in 2009 in the field of diagnostic modeling of technical parameters of power transformer-reactor electrical equipment. Now, he works as senior expert of Division of electrical equipment and transmission lines, Scientific and Technical Center of Federal Grid Company of United Energy System, Russia. The author has more than 200 scientific and technical publications. His main research interests concentrate in the field of Transformer Short-circuit testing, Transformer winding fault diagnostic, Frequency Response Analysis, Smart Grid and Information-measuring systems. He is CIGRE member and Prof. of Moscow Energy Institute, Russia.

**Roman V. Mazhurin** was born in Novocherkask, Russia, in 1977. He took his degree as Electrical Engineer at Novocherkask State University in 1999. The author has 15 scientific and technical publications. From 2000 to 2014 years he worked as inspector of South Branch of JSC "Federal Grid Company of the Unified Energy System".

**Pavel S. Radin** was born in Khabarovsk region, Russia, in 1983. He took his degree as Electrical Engineer at Far East State University in 2005. The author has 21 scientific and technical publications. He worked in Far East Branch of JSC "Federal Grid Company of the Unified Energy System".

**Tanya A. Khrennikova** was born in Togliatti, Russia, in 1994. She is a student of Moscow Energy Institute (Scientific Research University) now.