RIGA TECHNICAL UNIVERSITY

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DEVELOPMENT OF INTEGRATED EXPLOITATION APROACH TO DETERMINE TECHNICAL CONDITION OF HIGH POWER TRANSFORMERS

Summary of Doctoral thesis

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Hereby I confirm that I have developed this work submitted for consideration to Riga Technical University for Degree of Doctor of engineering sciences. The Doctoral Thesis is not submitted to any other university or institution for other scientific degree.

Gerard Gavrilov……………………………(Signature)

Date:...

The Doctoral Thesis is written in the Latvian language, contains introduction, 4 chapters, basic results and conclusions, list of references, 41 figures and illustrations, totally 118 pages. List of references contains 83 units.

CONTENTS

INTRODUCTION

Topicality of the subject of the Doctoral work

A transformer of high power (transformer) in a power system is one of the key elements determining safety of power supply. Its ability to operate with a particular load depends on the condition of its separate units and timely prevented defects that could cause the failures of the transformer. Fault of a high power transformer can result in an accident in power system with grave consequences.

Nowadays one of the problems to be solved for high safety maintaining is to provide an effective inspection of the technical condition of the operating electrical equipment - transformers. During the operation time the periodic inspection of high power transformer's technical condition includes preventive measures for its operational capability maintenance. At the detection of the defects at an early stage during the operation when an emergency situation does not threaten yet an opportune and correct decision made for these defects elimination provides a high factor of availability, decreases idle time and maintaining expenses as well as prolongs lifetime of the equipment.

The safety of transformer is directly connected with its lifetime. This time also defines assumed factors connected with the operational regimes. According to the norms [57, 77] the rising character of the curves of transformers' faults within the foreseen time of operation is similar to the correspondent characteristics of other equipment [83]. The most important feature of transformers is the determining of its operational lifetime mostly by the condition of paper-oil insulation during its natural ageing process and because of external factors.

The main factor causing the necessity in forced development of transformers condition inspection means and methods is the problems in its exploitation beyond the time foreseen in the norms. The rated lifetime of the majority of transformers being in operation is expired or comes to expiration. This situation, especially under the conditions of free market, requires paying a specific attention to the increasing of the total lifetime of transformers with more effective inspecting of their technical condition and optimization of the preventive measures [33].

The wastes of power supply enterprises existed because power supply failures take a significant part of all the economic accounts of the enterprises. The consumers of electrical energy require an uninterruptable delivery of power. During the last decade the demands in power increasing were very expressive, this tendency stabilized only during the last time in accordance with the economic situation in our state. The improvement of the power supply system requires high investments that are often limited. Investing into the modernization of power supply grids they therefore expose themselves to the risks of failures. The exploitation of such system needs the diagnostics of the equipment insulation that allows evaluation of the system's safety. The diagnostic methods that can be applied are different, but not all of them give information definitely identifying the ageing of insulation. The diagnostics should result in such amount of information that allows not only evaluation of the condition of insulation but prognosis of the equipment lifetime as well. The method of the complex diagnostics should contain the full review of the examined object; in other case safety of the equipment will not be evaluated correctly therefore the effectiveness of inspection system of technical condition and diagnostics of high power transformers will be low. Uncertainty of the further development of the object under investigation can be decreased completing the information on it scientifically based for the decision making analyzing possible sequences of the decisions realization.

The current situation of the transformers park of LR TSO (Transmission Systems Operators of Latvian Republic) and for years gathered professional experience demonstrated that in most of the cases under the conditions of competition the prolongation of the transformers operation lifetime for 20-30 years is more profitable than their substitution for new. For example, in Russia the final expenses of modernization of TRDN-40000/110 type transformer account for 30 - 40% of the purchasing of a new transformer [83]. Therefore it is of high significance to find a suitable exploitation approach allowing obtain results similar to those obtained with regular inspection and therefore save the fund of enterprises [11, 13].

The determination of the current condition of a transformer and prognosis are still of top importance as the average age of the equipment at transformer park of LR TSO on 01.01.2012 is 31 years [65]. At the moment the economic situation can insist the enterprises not only on the prolongation of the transformers operation lifetime but in some cases on the increasing of loading and decreasing of the expenses. A wide review of the determining of high power transformers technical condition allows application of different maintaining methodologies selecting at the same time one the most accurate and suitable for the conditions of our country with an opportunity to combine them.

The object of the investigation, purposes and tasks

The object of the investigation of the Doctoral work is LR TSO high power transformers. The purpose of the Doctoral work is to develop and suggest the methodology of evaluation of the technical condition index (TCI), applying the integrated exploitation approach with the optimized amount of diagnostic measurements. As well as to apply the methods of technical condition and prognosis evaluation to determine the condition at the given moment and for the further operation period to provide maintenance of the transformers park and proposals for renovation. For the achievement of the purposes it is necessary to involve a complex diagnostics of the transformers.

The extent of the diagnostics depends on the particular task assigned for the inspection to detect for the transformer with defects indicator the functional condition, the opportunity of its further exploitation without regulate service, the extend of the service measures necessary for the prolongation of the lifetime. The tasks assigned for the optimal diagnostics are the following:

- to bar from the repetition of similar failures in the same or of similar type of transformers;
- to determine possible and irreversible disturbances;
- to evaluate the level of wear of the equipment and propose possible measures for the equipment renovation.

The defining of the remained period of exploitation of the equipment, application of the determining algorithm of technical condition and evaluation criteria are also considered as the tasks of the research as well as selection of the approach to the application in accordance with technical opportunities consisting in its turn of the subtasks:

- analysis of the object essence (from the technical point of view), features and tendencies of the defect progressing;
- generalization of the specialists opinions on the opportunities of the development (improvement of the technical condition) of the transformer under research;
- scientifically proved evaluation of the sequences of the made decisions.

Scientific novelty of the Doctoral work

The Doctoral work presents developed and applied in practice integrated and in this way improved approach to the maintenance of high power transformers in Latvia, combining in its turn best solutions of two maintaining approaches. Mainly the attention is paid to the combining of regularly organised (TBM) and in real conditions determined (CBM) maintenance approaches. The proposed maintaining approach is considered as an improved also because in addition it contains an optimised extend of complex diagnostics and the determination of the minimum amount of first stage measurements of the testing algorithm.

For the methodology of the evaluation of high power transformers technical condition index (TCI) the exploitation approach of real condition determination is used, being customized to LR TSO conditions and included into the united and optimised diagnostic algorithm.

Means of the research, methods and restrictions

The means of the promotion work are: methodology of determination of high power transformers technical condition index (TCI), methodology of evaluation of technical condition prognosis and applied approach of the transformers maintenance and risk analysis of the transformers failures.

Data are mathematically processed by means of MS Excel software. It allows determine the correlation between two characteristic values of solid insulation.

Application of the risks matrix provides a good visualization for distribution of risks and their close orientation that finally is applied for the determining and inspection of the transformer technical condition.

The restrictions of the Doctoral work are some characterising of technical conditions features of solid insulation of high power transformers (insulation measurements, (absorption factor), transformer oil breakdown voltage, amount of moisture in solid insulation as well as in transformer oil), as in some cases they were obtained with different measurement devices that in their turn influence the results of measurements and diagnostics judgment as a whole.

Applied significance of the research

The integrated maintaining approach with optimised diagnostic complex developed in the Doctoral work gives an opportunity to provide an inspection of the existing transformers park with the evaluation of a separate high power transformer technical condition with the purpose of prognosis of the transformer possible lifetime and according to this to make decisions about the service and renovation of the high power transformers.

Approbation of the research

1. 2011 IEEE PES. Innovative Smart Grid Technologies Conference Europe (ISGT Europe). Manchester, Great Britain, December 05-07, 2011. Report:”Technical Condition Asset Management of Power Transformers”.

2. 52nd RTU International Scientific Conference. Power and Electrical Engineering. Riga, Latvia, October 13-14, 2011. Report: “Identification of Power Transformer’s Failure and Risk Source”.

3. International Conference TLM-2011 “Transformer Life Management”, Hanover, Germany, June 06-07, 2011. Report: “Mineral oil-impregnated electrical equipment in service. Interpretation of dissolved and free gases analysis”.

4. IEEE PES PowerTech-Trondheim 2011. Trondheim, Norway, June 19-23, 2011. Report: “Power Transformer’s Fault Prognosis”.

5. IEEE IES CPE11. International student forum. Doctoral School of Energy and Geotechnology II. Tallinn, Estonia, June 03, 2011. Report: “Insulation oil treatment and its’ necessity in power transformers”.

6. IEEE IES CPE11, **7th International IEEE Conference-Workshop Compatibility and Power Electronics, CPE 2011. Tallinn, Estonia, June 01-03, 2011. Report:** „Useful Lifetime and Rational Replacement of Power Transformers”.

7. CWIEME, INDUCTICA 2011. Berlin, Germany, May 24, 2011. Report: „Distinction of Power Transformer’s Solid Insulation and its’ Impact on Conclusion of Technical Condition”.

8. ECT 2011. The **6th** international conference on electrical and control technologies. Kaunas, Lithuania, May 5-6, 2011. Report: „Moisture presence in insulation oil. Oil degradation effect on solid insulation of electrical equipment”.

9. 10th International Symposium. Topical Problems in the Field of Electrical and Power Engineering. Pärnu, Estonia, January 10-15, 2011. Report: „Power transformers diagnostic”.

10. 51nd RTU International Scientific Conference. Riga, Latvia, Oktober 14-16, 2010. Report: „Measuring specificities of dissipation factor of electrical equipment in substations”.

11. The 5th International Conference on Electrical and Control Technologies. Kaunas, Lithuania, May 06-07, 2010. Report: „Technical condition and remaining lifetime assessment strategies of power transformers”.

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1. Gavrilovs G., Vitolina S., „Identification of Power Transformer’s Failure and Risk Source,” RTU, The 52nd International Scientific Conference. Power and Electrical Engineering, October 2011, Riga, Latvia, p. 4.

2. Gavrilovs G., “Technical condition asset management of power transformers,” IEEE-PES ISGT Europe 2011 Manchester, p.5.

3. Gavrilovs G., Vitolina S., Borscevskis O., „Power Transformer’s Fault Prognosis,” *in Proc. IEEE PES PowerTech 2011-Trondheim,* p. 7.

4. Gavrilovs G., Borscevskis O., “20kV Voltage Adaptation Problems in Urban Electrical Networks,” *in Proc.* ***7th International IEEE Conference-Workshop Compatibility and Power Electronics. International Student Forum****, Doctoral School of Energy and Geotechnology II,* IEEE IES CPE11, pp. 68-71.

5. Gavrilovs G., Borscevskis O., "Insulation oil treatment and its' necessity in power transformers," *in Proc.* ***7th International IEEE Conference-Workshop Compatibility and Power Electronics. International Student Forum****, Doctoral School of Energy and Geotechnology II,* IEEE IES CPE11, pp. 23-27.

6. Gavrilovs G., Borscevskis O., „Useful Lifetime and Rational Replacement of Power Transformers," *in Proc.* ***7th International IEEE Conference-Workshop Compatibility and Power Electronics,*** IEEE IES CPE11, pp. 40-44.

7. Gavrilovs G., „Distinction of Power Transformer's Solid Insulation and its' Impact on Conclusion of Technical Condition," conference material of CWIEME, INDUCTICA 2011, p. 8.

8. Gavrilovs G., „Moisture presence in insulation oil. Oil degradation effect on solid insulation of electrical equipment," *in Proc. 2011 of The 6th International Conference on Electrical and Control Technologies ECT-2011,* pp. 272-275.

9. Gavrilovs G., O. Borscevskis, „Replacement of Power Transformers basis on Diagnostic Results and Load Forecasting," *in Proc. of World Academy of Science, Engineering and Technology 2011,* WASET, year 7, issue 76, ISSN 2010-3778, pp. 181-186.
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14. Gavrilovs G., Vītoliņa S., „Solid insulation drying of 110 kV paper-oil instrument transformers". 50th International Scientific Conference Power and Electrical Engineering, Oktobris 2009, Rīga, Latvija. RTU zinātniskie raksti. 4. sēr., Enerģētika un elektrotehnika. - 25. sēj. (2009), 35.-38. lpp.

15. Gavrilovs G., Vītoliņa S., „High power transformers' development tendency of maintenance strategies", Energy and World, volume 2009/9, p. 9.

Structure and size of the thesis

The Doctoral thesis contains the introduction, 4 chapters as well as main results of the work, conclusions and list of references containing 83 sources of information. The total size of the thesis is 118 pages. The thesis contains also 41 figures and 27 tables.

1. COMPLEX DIAGNOSTICS OF HIGH POWER TRANSFORMERS

The first chapter overviews the whole amount of complex diagnostic measurements of high power transformers and its application substantiation with economic effectiveness. Basic stages of the complex diagnostics and optimization of the existing methods of technical condition determination are summarized in details as well as the chapter informs on LR TSO transformers disconnection at a stretch, its reasons and modernization attempts.

A large attention is paid to the quality of electrical energy as one of the key areas of electrical engineering and the prevailing reason for it is the sensitivity of a final consumer. LR TSO provides the service in transmission network around all the territory of Latvia. The transmission systems should guarantee the operators with the safety and quality of electrical energy supply by 110 kV and 330 kV electrical transmission network. With this aim the operator services the transmission lines, provides the exploitation, repairing and maintaining of the electric equipment installed at the substations (including diagnostics - preventive measurements). The main factor causing the necessity in forced development of transformers condition inspection means and methods is the problems in its exploitation beyond the time foreseen in the norms. The rated lifetime of the majority of transformers being in operation is expired or comes to expiration. This situation, especially under the conditions of free market, requires to pay a specific attention to the increasing of the total lifetime of transformers with more effective inspecting of their technical condition and optimization of the preventive measures using different maintaining approaches and methods of technical condition evaluation. In these activities one of the leading organizations CIGRE (International Council on Large Electric Systems) takes part.

The full rated lifetime of transformers (according to the State Standard of the Russian Federation (GOST), IEC standard produced transformers $\geq$ 25 years) depends on the condition of solid insulation, load, cooling system, protection and other factors [37, 54, 76]. It means that the remaining lifetime of the same age transformers operating under different conditions can be different. It is confirmed by the successful operation of the transformers produced at the beginning of the 60s as well as by the emergency situations at the substations of new type in Latvia and neighbor states, fig.1.1.

The main purpose of the diagnostics is to evaluate the condition of the object under diagnostic process. The information obtained during the diagnostics should be versatile and unambiguous. It should represent the condition of the object's insulation on the basis of the obtained information. The diagnostic method should get full overview of the object under investigation otherwise the safety of it will not be evaluated properly.

Fig.1.1. Burning of high power transformer

The basic stages of the complex diagnostics and integrated maintaining completed by the transmission operators are listed in Table 1.1 [77]. A wide range of LR TSO diagnostics methods (Table 1.2.) give an impartial enough information about all the units of transformer, as an output information [34] is taken.

Table 1.1.

Basic stages of the complex diagnostics

1.	**Analysis of the regular defects and failures rate of transformers of particular type** ⇩
2.	**Maintenance of transformer and gathering of technical information** (about operation regimes, load, specific of exploitation, climate conditions, air pollution, etc.) ⇩
3.	**Analysis of the technical information and results of service measurements** ⇩
4.	**Taking of oil samples and their physical-chemical laboratory analysis** ⇩
5.	**Measurements of transformers operating in no-load and loading regimes** (measurements of partial and disruptive discharges, their location detection with acoustic devices, thermography testing of all units of transformers, examining of reservoirs and cooling systems oil pumps for vibration) ⇩
6.	**Regular electric measurements for disconnected transformer** (resistance of windings and wires insulation and tgδ, active resistances of the windings, losses of no-load shirt-circuit regimes, etc.) ⇩
7.	**Preparation of technical reports** (results of testing, analysis of the results, conclusion on the transformer condition, etc.)

The measurement methods are time-consuming and expensive for the overall transformer inspection, therefore the selection of testing parameters is optimised taking place at several stages. The proposed methodology of the determination of technical condition is optimised basing on the previous experience and diagnostics data obtained during the maintenance period. It should be added that the conventional measurements mentioned in the 6th point of the basic complex diagnostics stage are supplemented with the testing of solid insulation with 5000 V voltage, the readout of which takes place at 15 and 300 seconds as well as with unconventional testing scheme of transformer winding insulation and C2 measurement scheme for RIP insulation of cables.

Table 1.2.

Methods of evaluation of separate units of power transformers and condition of system

Methods of diagnostics	**Elements of transformer**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Mainly the evaluation of locations of possible failures is maid based on the analysis of analogue type transformer defects	+	+	+	+	+	+	+
Analysis of operation regimes, maintenance and repairing documentation, measurements	+	+	+	+	+	+	+
Overview of equipment					+	+	+
Chromatographic analysis of oil	+	+			+		+
Physical chemical analysis of oil	+			+	+	+	+
Detection of mechanical impurities in the oil structure				+	+		+
Detection of the level of polymerization of winding insulation	+						
Detection of the amount of antioxidants in oil				+	+		
Detection of residual resistance of oil against oxidation				+	+	+	
Infrared spectroscopy of oil	+	+		+	+	+	
Detection of the amount of furan in oil	+					+	
Detection of oil tgδ and breakdown voltage of at different values of temperature	+			+	+	+	+
Analysis of silica gel of thermal siphon filters	+			+	+		
Detection of the windings and cables insulation characteristics at different values of temperature and voltages including zones (additional schemes, 5000 V).	+					+	
Calculation of solid insulation moisture according to balanced condition - paper-oil - and defined values of insulation characteristics.	+					+	
Determination of partial discharge *	+	+				+	
Thermography testing of transformer *	+	+			+	+	+
Testing of reservoirs *, oil pumps and cooling system of transformer for vibration		+	+		+		
Detection of short-circuit resistance			+				
Detection of no-load current and losses including those at rated voltage		+					
Detection of oil volume in the reservoir at different temperatures					+		
Detection of oil pressure in the cable insulators at different temperatures						+	
Complex measurement of cable insulators solid insulation (including C2 scheme)						+	
Detection of winding and other contacts transient resistance at different conditions of contactor							+
Readout of circle diagram and oscillogram of contactor operation							+
Measurements of oil pumps and fans phases					+		
Complex analysis of the obtained results	+	+	+	+	+	+	+
* is made in two regimes - high loads and no-load							

It should be noted that the optimisation of the applied methodology (decreasing of methods because of application effectiveness) does not result in the decreasing of consistency.

Taking general accepted diagnostic algorithms and CIGRE investigations [31] as often applied diagnostic tests allows make analysis resulting in the conclusion that some of the diagnostic tests have an informative character only or duplicate the information already obtained by means of other methods and view of the formed defect. Therefore it is possible to refuse purposively from some of them or to replace them with those of other type. The modified inspection algorithm of high power transformer that could be applied in the united improved maintaining approach is represented in figure 1.2. The measurements of the first stage of this algorithm provide minimum of the necessary information on the general technical condition of transformer and give the possibility to detect the most significant defect formed in transformer that is accepted as the minimum of testing of the first stage.

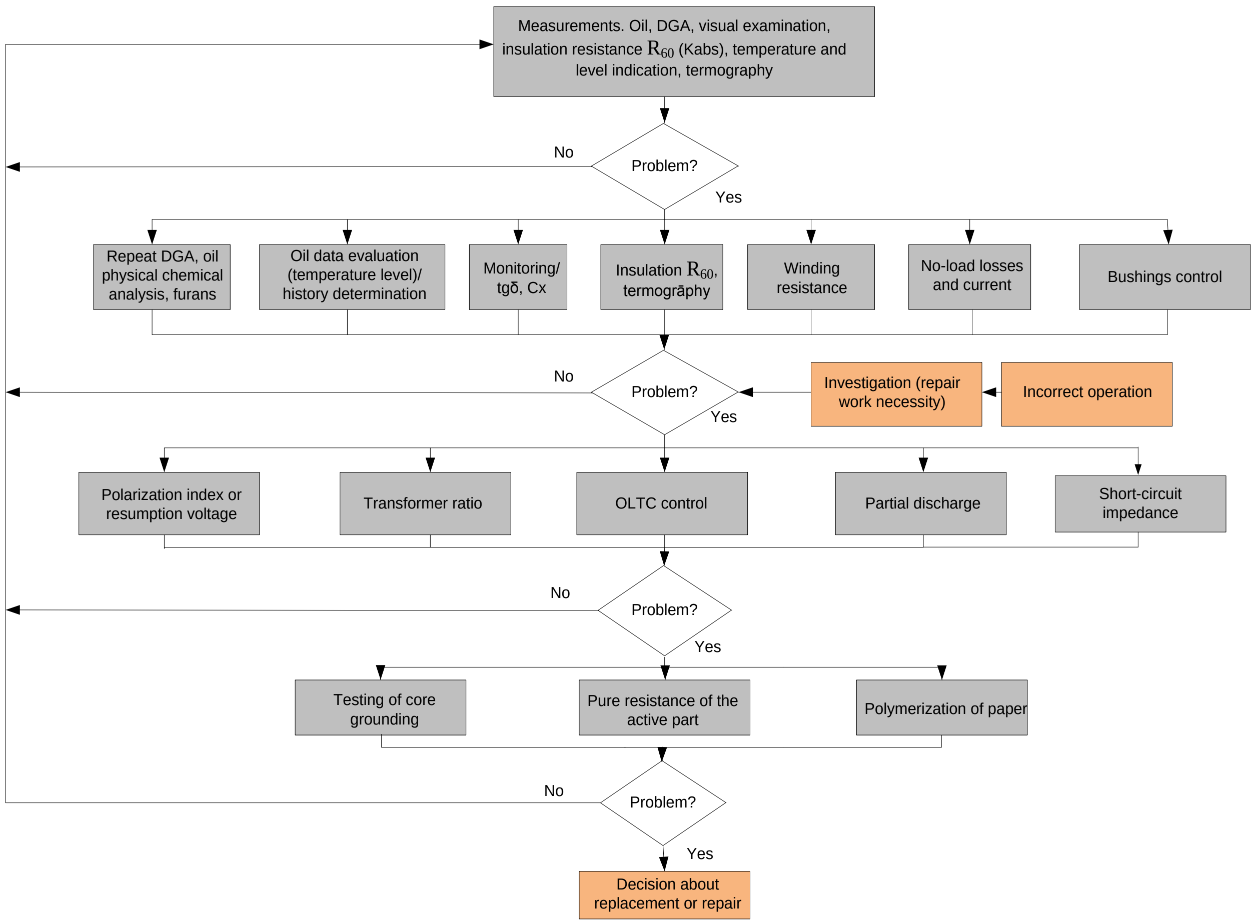


Fig.1.2. Optimised algorithm of the diagnostics

The Doctoral thesis contains the proposed and realised optimal algorithm of complex diagnostics effectively applied and giving positive results.

2. APPROACHES TO THE MAINTENANCE OF TRANSFORMERS

The second chapter considers the existing approaches to the transformers maintenance with their typical features and conditions. The approach is described on the basis of real technical condition with its elements. The modern problems of the transformers park are reflected and the necessity of integration of two most suitable for LR TSO maintaining approaches integration is defined. The development of the integrated approach is validated.

The organization of preventive measures plays a key role in the maintaining of transformers technical condition and operation capability. The attention should be also paid to the types of exploitation approaches (strategies) and their selection in accordance to the present situation in power system, detection of remain lifetime of high power transformer using risk analysis and methods of prognosis with the most suitable algorithm.

Figure 2.1 represents different types of maintaining approaches of modern applied electrical equipment including high power transformers [13, 44].

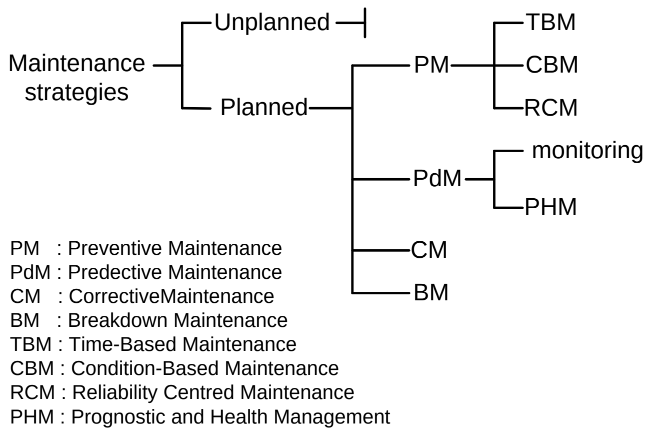


Fig.2.1. Basic types of the electrical equipment exploitation approaches.

Preventive Maintenance (PM) provides the diagnostics and service of the equipment within the particular periods of time and in accordance with the above mentioned criteria with the purpose to reduce the probability of the defects or weakening of functionality [73]. In the case of Time-Based Maintenance (TBM) of the system the frequency of inspection is defined according to the mathematical expectation of defects in transformer. In accordance with the real technical condition of the object the system in exploitation (*Condition-Based Maintenance **CBM***) is based on the independent inspection of this condition and detection of defects at early stage. This approach is directed to the decreasing of possible undiscovered failures, prolongation of the transformer operation lifetime as well as to the decreasing of the expenses assigned for repairing and service. More advantages are given with the maintaining system allowing continue the operation with defects in the case if the risk of defects is acceptable (*Reliability Centred Maintenance* ***RCM***) [57]. The necessary safety in these cases is provided by optimization of operation regimes, minimizing the connection of the equipment, extending uninterruptable inspections, applying expert systems, etc.[8]. Predictive Maintenance (PdM) is the exploitation approach realised according to the prognosis obtained as a result of significant analysis and evaluation of the object parameters weakening [73]. The most important purpose of PdM approach is to provide the service and repair of the object at the moment when the correspondent maintaining is the most effective from the technical as well as economic point of view.

One of the new approaches is Prognostic and Health (technical condition) Management (PHM) including a lot of functional possibilities like, e.g. determination of defect and its localization, the tendency of the equipment operation weakening, remain lifetime and probability of faults and technologies of prognosis of other parameters, etc [44]. Corrective Maintenance (CM) is realised when the faults are discovered to set the object into the condition when it could complete the necessary operations [73]. The operation of CM approach provides the testing and/or repairing (replacement) of the equipment in accordance with previously planned schedule. Breakdown Maintenance (BM) – is the approach which unlike those above mentioned foresees the inspection and repairing of the equipment only after the fault for the recovery of its operation capability. BM is applied only for the equipment the faults of which does not result in significant decreasing of safety of power supply and the repairing expenses of which are low.

The key point in the organization of preventive measures is connected with the replacement of the approach from the periodically organised TBM for the new preventive system CBM or other optimised being dependent on the condition of the object. Evaluating each separately maintaining approach in details the specialists of LR TSO should make a decision about that most suitable for the power system taking into account the features and requirements of it. During a long period of time within the frames of the Doctoral work TBM and CBM maintaining approaches were evaluated in details as independently existing as well as both giving technical and economic profit being integrated. For the TBM approach diagnostic software was developed with a particular amount of measurements without taking into account the previous technical condition of the transformer and measurement results. Application of the maintaining approach based on time only (TBM) results in the risk that the transformer earlier or later will be disconnected because of inside faults or even after those.

Therefore it is of top importance to organise the activities that could consolidate and improve the currently applied maintaining approach. As one of the suitable variants the author of the Doctoral work proposes to use the approach of real condition determination (CBM).

There are many variations of CBM algorithm that could be applied for the technical service of transformers. Only the gathering and testing of diagnostics results give practical overview of a particular model (algorithm). This is an ambient example of technical maintaining accepted at LR TSO, fig.2.2 [48, 50, 53]. This algorithm and approach are closely connected with everything mentioned in Chapter 1 and presented in fig.1.2.

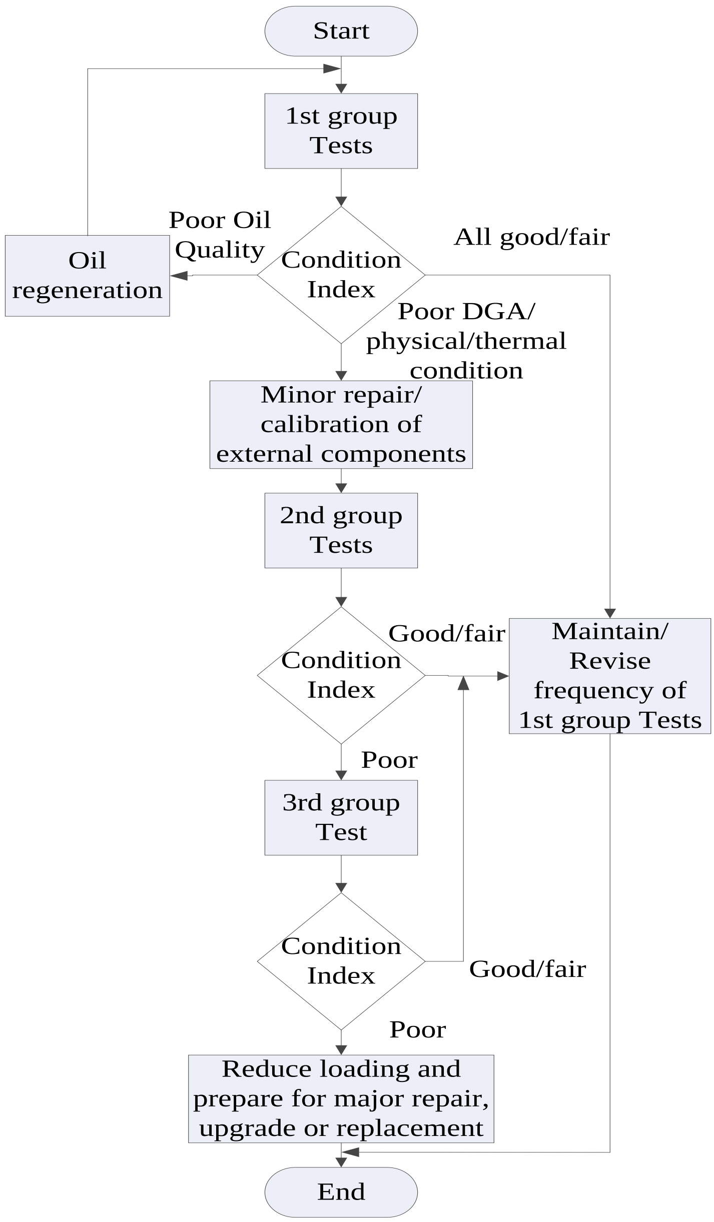


Fig.2.2. CBM application for the existing transformers

Table 2.1.

CBM algorithm group testing

Groups	Methods of inspection	Condition of transformer
1 group testing	Analysis oil / DGA	In operation
	Testing of the physical operation condition	In operation
	Visual examination	In operation
	Infrared thermography	In operation
2 group testing	Partial discharge	In operation
	Transformation coefficient	Disconnected
	Testing of cables insulation	Disconnected
	Testing of solid insulation	Disconnected
	Dielectric loses/ capacities	Disconnected
	No-load current and power losses	Disconnected
	SRI testing	Disconnected
	Short-circuit resistance	Disconnected
3 group testing	Testing of core grounding	At plant
	Pure resistance of the active part	At plant
	Polymerization of paper	At plant

Table 2.1 gives an opportunity to realise at what moment according to the algorithm of CBM the necessary amount of particular measurements is required. It is necessary to follow the algorithm to provide a qualitative realisation of works connected with the repairing and maintaining and to determine precisely a real technical condition of transformer and predict its remaining lifetime. The key proposal for the maintaining approach to detection of technical condition is the approach to use the obtained measurement results/technical data. Due to these results and their analysis we can predict the further technical operation and define its importance.

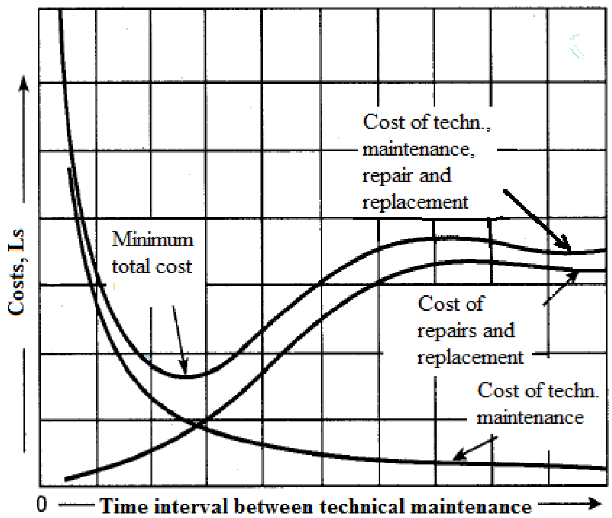


Fig.2.3. Impact of the transformer maintenance on expenses

Fig.2.3 results in the conclusion that the amount of technical service activities is directly proportional to the total expenses. The more unreasonable technical service works are completed the higher are the total expenses because of high expenses for the maintaining of equipment. If the technical service is less completed then the total expenses will be nevertheless high due to the unforeseen additional expenses for the transformers technical condition maintaining or changing. Thus it is of top importance to decide on the amount and frequency of technical service resulting in the reducing of total expenses. Such economic effectiveness is achieved applying an integrated maintaining approach. In other words the maintaining expenses are sharply decreased and with the increasing of repairing and changing expenses the total increasing of expenses will not be so fast if the period of the technical service increases and minimum total expenses are decreasing more.

All the information of the 2d chapter results in the conclusion that it is necessary to consider purposefully the improvement and optimization of the maintaining approaches. TBM and CBM maintaining approaches are accepted as the most suitable for the Latvian and LR TSO conditions. Mutually integrating these two approaches and extracting from them only the best ideas, aspects and nuances result in a new unique maintaining approach with an opportunity to plan, make a prognosis and change any maintaining activity. It is obvious that for each transformer this approach should be individual. The main advantage of the integrated maintaining approach is its permanent yielding to optimisation and allows the use of such other risks from other approaches like prognosis of technical condition and determination of risk condition.

The integrated maintaining approach proved its application at LR TSO transformer park service. According to the investigation the positive results were demonstrated with the transformers with the servicing lifetime above the rated exploitation time, i.e. above 25 years for the transformers produced according to GOST standards.

The method in practice consists of the organization of inspection of the transformer's main units and elements and its technical condition at least once in accordance with the documentation of internal norms. For the further following the tendency of the changes of technical condition the next term of the inspection can be changed depending on the real technical condition of the transformer. Periodic activities of the technical service and terms of diagnostics can be observed in Table 2.2 [67].

Table 2.2

Application of transformers integrated maintenance

No.	Type of the element	Term of inspection, years				Notes
		Analysis of oil	Chromatography of gas	Technical maintenance	Diagnostics	
1.	330kV transformers	2*)	6months **)	1	4***)	*) After the works connected with the full change of oil, at once after it and any of its processing.**) After actuation of basic protection equipment (gas, flow, differential). After degasification works.***) Before exploitation, after modernisation works, after disconnections (if necessary).
2.	Devices of voltage regulation (SRI) (produced	-	-	1	4*)	*) Together with transformer diagnostics or after step switching and changing of operating device.
3.	110kV transformers	4*)	6months **)	1	8***)	*) Before exploitation, after oil changing, after modernisation. **) After actuation of basic protection equipment (gas, flow, differential), after degasification. ***) Before exploitation, after modernisation works, after disconnections, after rigging.
4.	110kV (SRI) contactors (produced according to GOST)	1*)	-	1	8**)	*) After changing of oil, the change of oil is realised according to the results of oil testing or after the particular amount of switching operations. **) Together with transformer diagnostics, after repairing.

3. IDENTIFICATION AND PROGNOSIS OF TECHNICAL CONDITION OF HIGH POWER TRANSFORMERS

The third chapter considers the factors influencing during the period of transformer maintenance and such technically important aspects like diagnostics of defects, analysis of faults, prognosis. The author considers and proposes the essence of transformers remain lifetime detection, features of ageing of solid insulation, as well as methodology of determining of technical condition index (TCI), applying the integrated maintaining approach. The chapter contains an example for the determining of interoperation of two parameters characterising solid insulation and a correlative testing of the results of measurements obtained during maintaining.

During the exploitation of transformer a permanent slackening of winding mounting, wear of insulation, plastic strain of paper and cooper caused by dynamic loads resulted from the faults of the network, short-circuits, etc. Besides that each transformer has own mechanical parameters pressing the construction and own safety factor calculated for particular short-circuit currents according to the power of the supply network, etc. Moisture also has significant importance. The side effect of the solid insulation (cellulose) wear is extraction of water. During the transformer operation lifetime the cellulose insulation subjected to the influence of heat cycle causing the wear of insulation material [46].

The full rated operation lifetime of transformer directly depends on the construction of the transformer, producer, modes of network and inspection, maintaining regulations and measures, diagnostics and repairing. The determination of technical condition of some of the transformer groups is not permissible. Each transformer should be inspected individually taking into account its exploitation report including the results of diagnostics as well as activities of technical service. The factors impacting within the period of transformer lifetime simply can be represented as in fig.3.1 [51].

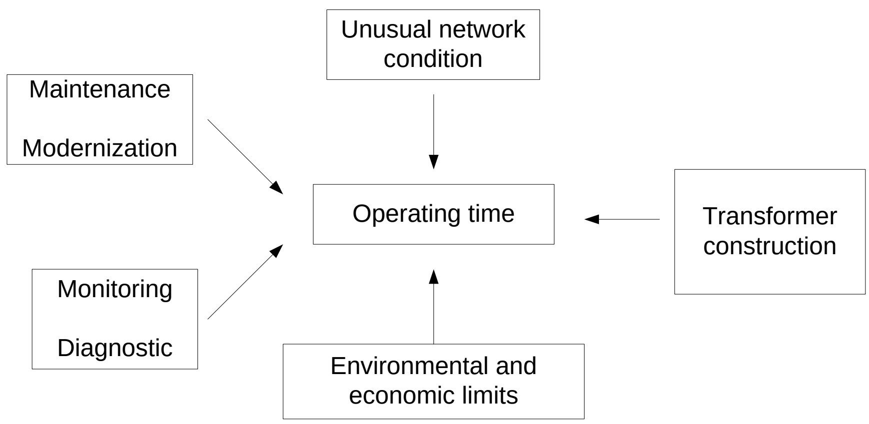


Fig.3.1. Components of the transformer maintaining lifetime

Remain lifetime (duration), factor of technical condition of the transformer (TCI), technical service factors, results of diagnostics, technical condition - that all is for the component failures prognosis and real methodology modelling. The above mentioned information can provide evaluation of the remain lifetime of the transformer, in accordance with the factor of transformer technical condition (TCI), provide with a conclusion about the system faults consequences and about probability of failures. Fig.3.2 represents the overview of full rated lifetime of transformers and influence of system regimes on it [10].

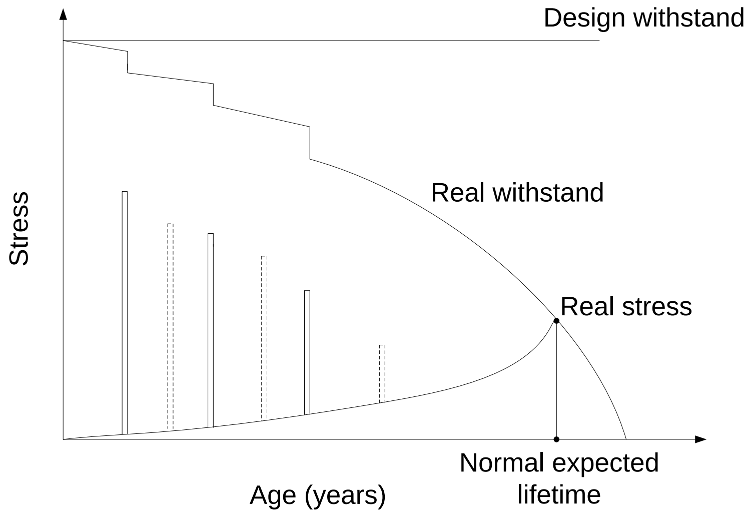


Fig.3.2. Full rated lifetime of transformer

The remain maintaining lifetime or with other words - *recourse* is inversely proportional to the transformer effective time period. The main aspect to be taken into account is that some elements of the transformer system (park) can not be renewed, due to the construction of transformer. *Physical resource Kf* exists for such transformers. The renewable transformers, except physical resource, have also *an obsolescence resource Km* [62]. The remained maintaining lifetime (L_{REM}) for the transformer connected to electric supply during the period of one hour *t*, is calculated in the following way:

$$L_{REM} = \frac{1}{K}\left(\frac{1}{pd_l} - \frac{1}{pd_p}\right), \quad (3.1)$$

where K – is a factor of deterioration;

pd_l – is a paper insulation polymerization level at the end of maximum real exploitation period;

pd_p – is a paper insulation polymerization level during the testing time.

The mentioned above information results in the conclusion that the general technical condition of the transformer insulation is conditioned by that of solid insulation and transformer oil. The deterioration from moisture becomes even more dangerous without electrical strengthening of solid insulation as the moisture gets into oil and makes beads during the sharpen heating transient processes, fig.3.3. It also results in the reducing of electrical strength. The increasing of moisture in paper is directly connected with the increasing of dielectric losses as well as insulation conductivity decreasing at the same moment electrical durability of insulation.

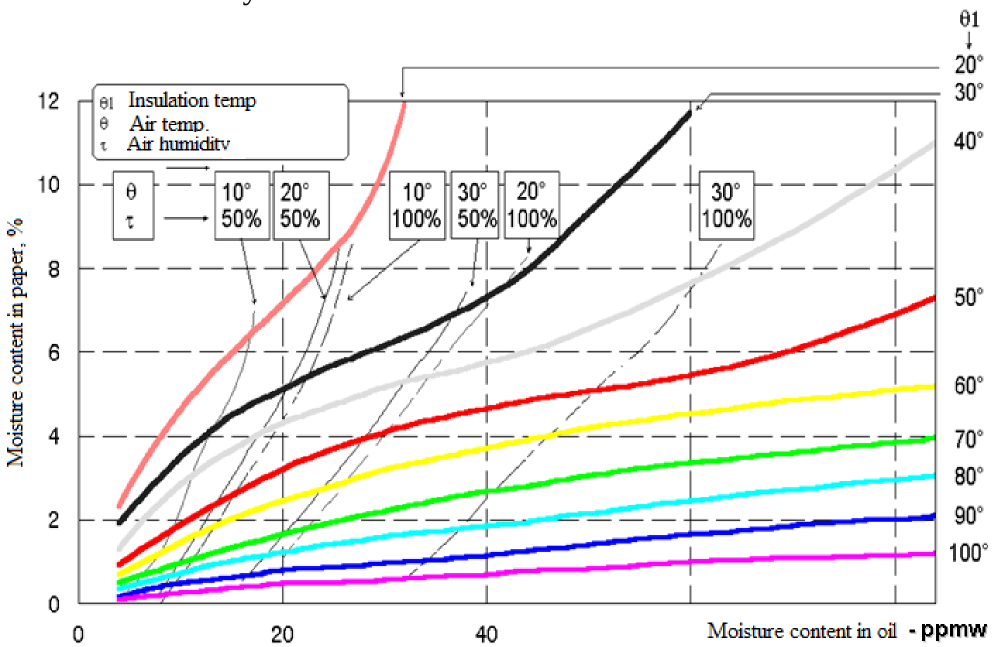


Fig.3.3. Content of moisture in oil and insulation dependence on temperature

Description of an example: each parameter should be defined with a factor. The factor is given in the way of function, where X-direction defines the measurement of the parameter and Y-direction - its factor, the example of one parameter is presented in fig.3.4. The factor is in the range from 0 to 1. The higher is the factor the better is considered the oil. Having obtained a factor for each parameter defines that general for the oil condition according to (3.2) [47].

$$F_{oil} = \min(F_{breakd}, F_{diel}, F_{acid}, F_{flash}, F_{moist}, F_{contam}), \quad (3.2)$$

where F_{oil} – is a general factor for the oil condition;

F_{breakd} – factor of disruption voltage;

F_{diel} – factor of dielectric losses;

F_{acid} – factor of the amount of acid;

F_{flash} – factor of fire temperature;

F_{moist} – factor of the amount of moisture;

F_{contam} – factor of mechanical impurities and category of purity.

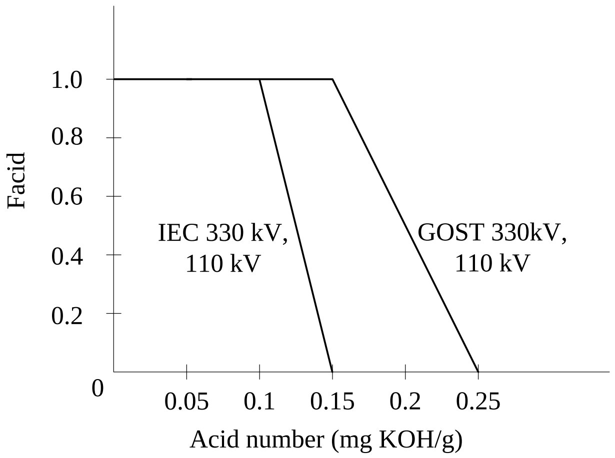


Fig.3.4. Factor of the amount of acid

The daily coefficient of lifetime reducing can be calculated according to (3.3) defining the percentage decreasing per day.

$$T_{RED} = \frac{F_{EKV.N.} \times 24}{T_{FROT}} 100, \qquad (3.3)$$

where T_{RED} – is the daily coefficient of lifetime reducing, %/ per day;

T_{FROT} – full rated operation lifetime of the transformer, hour.

For the calculation of percentage decreasing of total operation lifetime of transformer from that of rated planned it is necessary to sum up all the components of day T_{sam}:

$$T_{d\sum RED} = T_{d.RED} + T_{(d-1)\sum RED}, \qquad (3.4)$$

where $T_{d\sum RED}$ - is the total value of operation lifetime decreasing;

$T_{d.RED}$ – actual daily coefficient of operation lifetime decreasing;

$T_{(d-1)\sum RED}$ – previous total value of operation lifetime decreasing.

The condition of insulation of an aged transformer is approximately double worsened exceeding the operation temperature over 90 ^{o}C for each 6-8^{o}C.

It is necessary to note that there is also a similar method with quality criteria for the detecting of solid insulation condition that is described at the beginning of the chapter, but this method applies the descriptive criteria of the solid insulation [43].

To examine the accuracy of transformer technical condition determining and the information of technically obtained diagnostics of the measurements results and its application, the results are mathematically processed. Transformers of different groups with different operation lifetime periods have been taken. The attention was turned to the condition of insulation and two its characterising parameters: absorption coefficient Kabs and dielectric losses tgδ. These two factors were analysed and mutually connected according to the principle of correlation analysis. For example, for the mathematical process testing the results of measurements of the III group transformer of 1981 for the high voltage winding (A scheme) is given in Table 3.1.

Table 3.1

X-measurements results of the transformer

Year of inspection	Kabs	tgδ
1981	1.68	0.46
1989	1.12	0.13
1993	1.43	0.22
1994	1.29	0.2
1997	1.31	0.3
2004	1.51	0.34
2009	1.59	0.49

The graph in fig.3.5 reflects the inter correlation of both parameters and technically validated tendency of changes in accordance with the obtained results presented in Table 3.1.

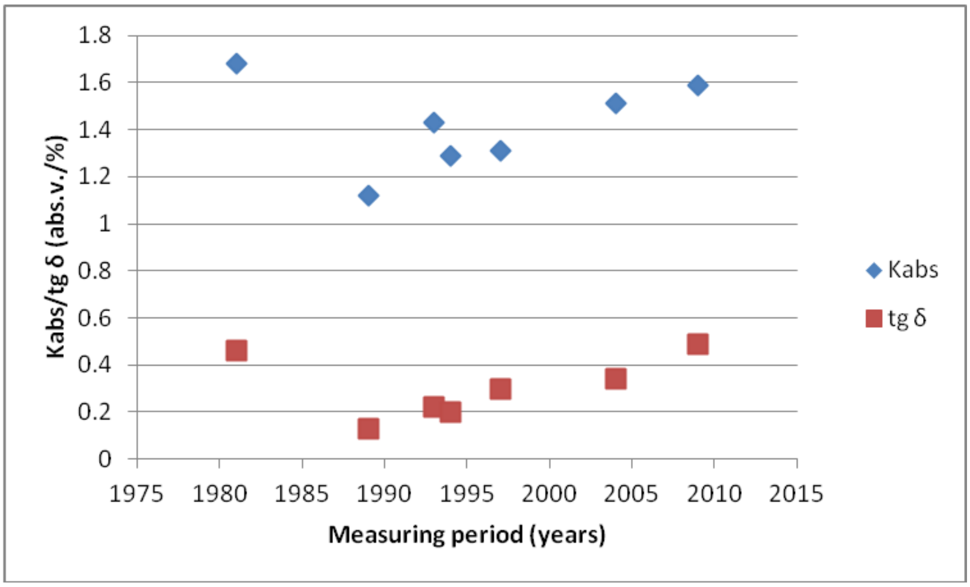


Fig.3.5. Graphical representation of the results of measurements

From the graph it is obvious that the measurement results reflecting the second point are the lowest. The second point is measured at the transformer rigging and connected load. Kabs and tgδ interconnection is observed in fig. 3.6.

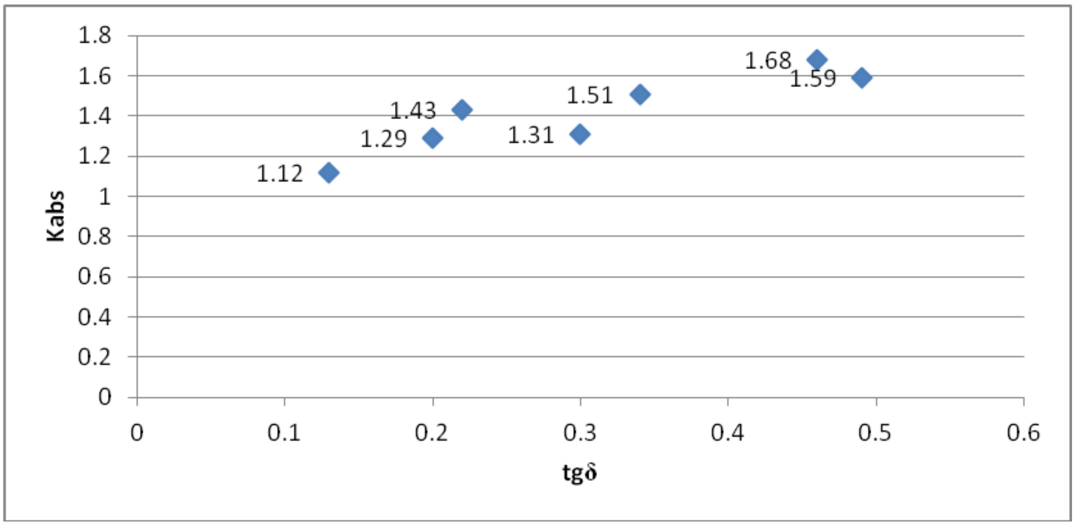


Fig.3.6. The curve of Kabs and tgδ parameters correlation

Theoretically the dielectric losses should increase and absorption factor decrease therefore they will be in negative linear correlation. But in our case a linear positive correlation takes place in their relation to the lifetime as well as in their both interrelation that can be explained with modernisation activities during the period of transformer maintaining. The value of the correlation factor r = 0.904053 demonstrates the strong positive linear connection between the indicators.

The determination of transformer technical condition index (TCI) is a complex process. It depends not only on the results of diagnostics but also on the integration of the results of technical service and loading reports, on the age and other factors of operation providing an objective and quantitative overview of the transformer technical condition. The methodology demands from each particular evaluation of the technical condition to be technically interpreted and compared with the indicator of the results of technical condition evaluation. The diagnostics methods mentioned in Table 2.1, should be supplemented with the indicator influencing the lifetime of the transformer. The indicator of the evaluation of technical condition is represented in Tables 3.2-3.6.

Table 3.2

TCI calculation of the first tested group

Indicator of condition	Stage (a)	Number of the level increasing (b)	Weight factor (c)	Total result of classification (d)
Chromatographic analysis of gas	3,2,1,0	20,12,-18,-20	1.2	(b) x (c)
Physical chemical analysis of oil	3,2,1,0	20,12,-18,-20	1.2	(b) x (c)
Physical examining of operation and visual inspection	3,2,1,0	20,12,-18,-20	0.4	(b) x (c)
Infrared thermography	3,2,1,0	20,12,-18,-20	0.6	(b) x (c)
Operation lifetime	3,2,1,0	20,12,-18,-20	0.4	(b) x (c)
TCI of the 1 group *(Sum of separate parameters)*				A
Period of the transformer exploitation above 100%				B
1final TCI of the tested group				A – B = C1

Table 3.2 considers all the diagnostic inspections and method, applied for obtaining the first group TCI. Each stage of individual technical condition classification indicator (a) 3, 2, 1 or 0 is multiplied with the numbers of classification increasing (b) : 20, 12, - 18 and - 20 respectively. The general result of classification (d) for each indicator of technical condition is the result of multiplication of the results of increasing classification (b) and weight factor given in Table 3.2. Then TCI of the first group is obtained summing up all the total classification results.

The result is defined within the range of percent for the real (predicted) exploitation period, as shown in Table 3.4. If the period of exploitation (predicted) is used for more than 100%, the results will be subtracted from the first group TCI, in order to obtain the final first group TCI and respectively, if the period of exploitation does not exceed the full rated, then value B is 0.

To assign the level of indicator detection of the transformer technical condition Table 3.3 is completed demonstrating an example of the indicator assignment according to the insulation resistance and dielectric losses tgδ.

Each parameter characterising the technical condition of transformer should be normalised with the validated technical documentation. In most of the cases the technical documentation is international standards. The evaluation of LR TSO transformers park technical condition uses a basic standard regulating technical maintenance, diagnostic testing and conditions of exploitation in accordance with IEC 60076. The GOST standard transformers are diagnosed according to similar principles but in accordance with [77] used as a key document for regulating conditions and norms of rejecting.

Table 3.3

The level of indicator for solid insulation resistance and dielectric losses

Parameter of insulation resistance R_{60}			
Measured value, MΩ	**Possible values/absorption coefficient**	**Level of indicators**	**Notes**
7950	<3900 MΩ and Kabs<1,0	0	Measurements should be realised at the same temperature
	3900÷5500 MΩ (50÷70% from the previous measurements and/or Kabs=1,1÷1,4	1	
	5500÷7000 MΩ (70÷100% from the previous measurements and/or Kabs=1,4÷1,6	2	
	>7000 MΩ and Kabs>1,6	3	
Parameter of dielectric losses			
Measured value, tgδ %	**Possible values/absorption coefficient**	**Level of indicators**	**Notes**
0,37	>1%	0	To measure at strongly assigned min.temperature
	increasing more than 50%	1	
	÷ 1% (for all transformers), but the increasing not more than 50 %	2	
	0,37÷0,45 (about 20% of increasing)	3	

Table 3.4.

Evaluation of the served exploitation time

Percentage evaluation of the served exploitation time	Result (B)
100% ≤ time of exploitation < 105%	10
105% ≤ time of exploitation < 110%	15
110% ≤ time of exploitation < 120%	20
time of exploitation < 120%	30

A similar method is available also for the second testing group TCI evaluation, demonstrated in Table 3.5. Taking into account the similar importance of the first and second group diagnostics methods weight factor 0.5 is adjusted for both indicators of the transformer technical condition TCI detection given in Table 3.6.

Table 3.5

TCI calculation of the second tested group

Indicator of condition	Level (a)	Number of the stage increasing (b)	Weight factor (c)	Total result of classification (d)
Transformation coefficient	3,2,1,0	20,12,-18,-20	1.0	(b) x (c)
Partial discharge	3,2,1,0	20,12,-18,-20	1.2	(b) x (c)
Testing of cables insulation	3,2,1,0	20,12,-18,-20	1.2	(b) x (c)
Resistance of solid insulation (Kabs, PI)	3,2,1,0	20,12,-18,-20	0.7	(b) x (c)
No-load current and power losses	3,2,1,0	20,12,-18,-20	0.7	(b) x (c)
Dielectric loses/ capacity	3,2,1,0	20,12,-18,-20	1.2	(b) x (c)
Short-circuit resistance	3,2,1,0	20,12,-18,-20	0.5	(b) x (c)
Device of the voltage regulation (SRI)	3,2,1,0	20,12,-18,-20	0.3	(b) x (c)
TCI of the 2 group *(Sum of separate parameters)*				D1

The testing of the third group consists of the testing of the core grounding, pure resistance of the active part, testing of paper polymerisation, and it is organised under the condition that the final TCI (summing up the parameters of the first and second group) is less than 60 and the question about the transformer writing off is brought up. In any case on the basis of the above mentioned testing results of the third group the arrangement of the results is made excluding them from TCI for getting final TCI that is demonstrated in Table 3.6.

Table 3.6

The calculation of the final TCI of transformer

Results of the testing group (a)	Weight factor (b)	TCI of transformer (c)
TCI of the first testing group	0.5	C1 x (b) = C
TCI of the second testing group	0.5	D1 x (b) = D
Total TCI		C + D
Core grounding testing of the third testing group (0, 5, 10, 15)		E
Testing of the pure resistance of active part of the third testing group (0, 5, 10, 15)		F
Testing of the paper polymerisation of the third testing group (0, 5, 10, 15)		G
The final TCI of transformer		(C + D) – E – F – G

Based on the boundary values given in Table 3.7 the final TCI of transformer defines the further maintaining activities.

Table 3.7

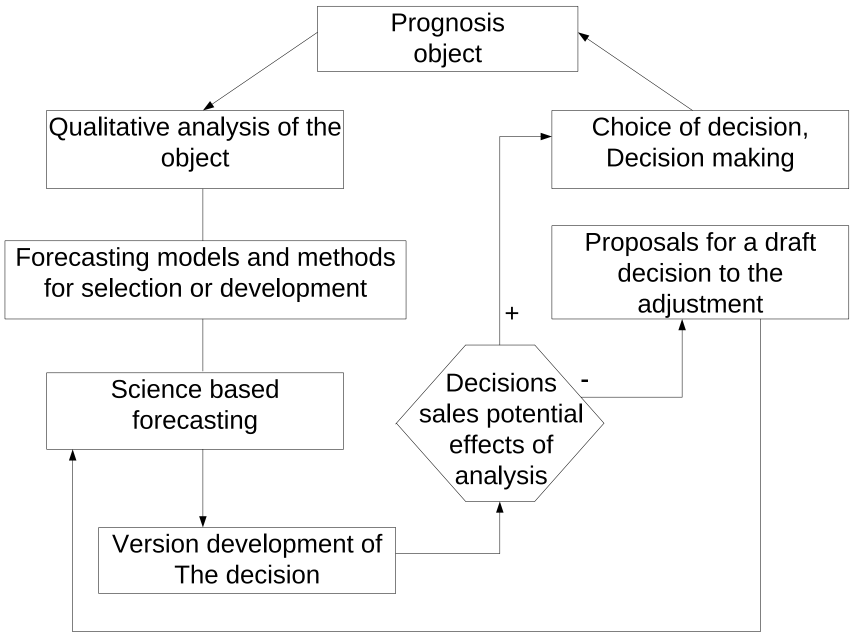
Level of the transformer technical condition

TCI boundaries	Evaluation	Recommendations for exploitation
$80 \leq TCI \leq 106$	Good	Can be used
$60 \leq TCI < 80$	Normal	CBM application (planning of testing)
$10 \leq TCI < 60$	Weak	Planning of the testing of the further group
$TCI < 10$	Very dangerous	Planning of complete inspection (recommend to impose a ban for exploitation

After that the results of groups testing (fig.2.2) are interpreted, the indicators are evaluated and summed up to define testing TCI of each group. If necessary the weight factor is adjusted. It is made in order to accept that one of the technical condition indices influences TCI to more or less than the others.

It is necessary to turn the attention to the period of exploitation and the significance of its impact on the total TCI evaluation. For example, two transformers similar in their technical conditions (without defects) produced under different condition and in different years: TDTNG 10000/110 1960, „ZTZ” and TNOR3E 16000/110 PN 2010, „ABB”. For the transformer produced according to GOST TCI is equal to 61.3 being up to the evaluation - normal, and for the transformer produced according to IEC standard TCI is equal to 80.8 also being up to the evaluation - good. In the essence of these two calculations there is only one difference - the number of increasing of exploitation time level that also influences the final result. Therefore in similar situations if it is more efficient to consider the planning of modernisation than the rejection of transformer from exploitation.

In rare cases TCI can be predicted that is often used for rating assignment for the existing transformers of the park with the aim to make a prognosis on the approximate amount of substituted transformers. The elaboration of a substantiated complex of prognoses requires information about the investigated object and the most significant factors influencing it. The importance of the prognosis results is proved also with qualitative analysis of the object and the feedback impact on the object under investigation (fig.3.7). Usually making decision in power engineering is a complicated task for only iteration demanding to do that in several steps.



3.7. Importance of prognosis in the development of the investigated object

The further prognosis of failures is the most important information for the service engineers group to avoid from the system downtime [1]. In order to make prognosis for the electric equipment, in this case high power transformers, it is required the direct connection with diagnostics, as the prognosis of transformers technical condition and remain lifetime is not possible without initial detection of failures. The elements of the equipment experience the highest linear increasing of faults during the final stage of the exploitation period. Usually the exploitation period of this equipment finishes at the moment when the curve of faults starts its linear increasing.

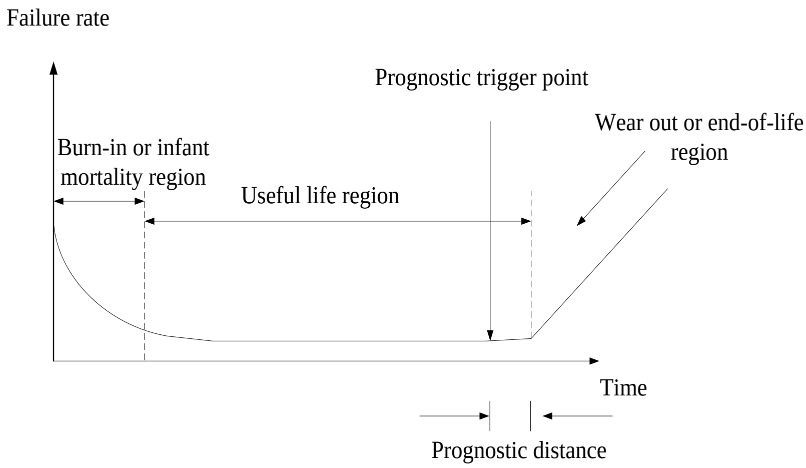


Fig.3.8. Bath-type curve (cycle of the transformer lifetime)

High power transformer's lifetime consists of three periods, demonstrated in fig.3.8. High power transformer lifetime prolongation is based on the using of diagnostics results and methodology of prognosis. The overview of the further technical maintaining works of real technical condition maintaining approach (CBM) depends on the present technical condition of the transformer and on the initial existence of failures. This approach is presented in the diagram in fig.3.9.

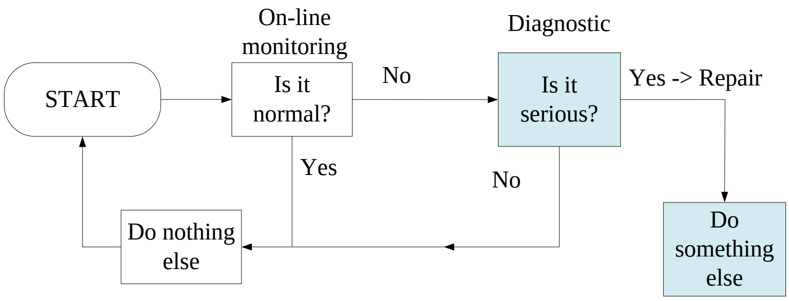


Fig.3.9. Diagram of monitoring and feedback logics of the diagnostics

It is important to realize the difference between the diagnostics of failures and that of faults.

Diagnostics of defects. Detection, presence, isolation and identification in the expected or started defect condition - the components exposed to influence (power systems, substation) are still operating in spite of the average lifetime exceeding the full rated.

Diagnostics of faults Detection, presence, isolation and identification of components (subsystem, system) interrupting the operation.

Diagnostics of the defects, isolation and identification are applied for the realization of the following actions:

- *Detection of the defects (faults).* An abnormal operation condition is detected and recorded.
- *Isolation of the defects (faults).* Detecting of a component (subsystem, system) operating with defect and not operating.
- *Identification of the defects (faults).* Evaluation of the defects (faults) characteristic and significance.

The producers of CBM/PHM system should follow the users regulations and agree all the purposes of the system. It is also possible to detect the general requirements connected with the regular diagnostics as well as the definition of specific demands for the systematized application. The realization of these responsibilities is provided by several departments dealing with the diagnostics and maintaining of the transformers park.

Mainly CBM/PHM system:

- Provides the improved technical maintaining and safety while the operation and service expenses are reduced;
- An opened system is realized providing the application of other methodologies;
- Rigidly controls the effectiveness of PHM ("weight");
- Meets the requirements of reliability, usefulness, applicability and long lifetime;
- Meets the requirements of monitoring, structure, expenses, compatibility and environment.

The order of implementation of defects diagnostics and prognosis techniques should be focused on the priorities to evaluate and propose the further effective actions for the accuracy of the algorithm of diagnostics and prognosis. The prognosis discovers unique challenges for long life prognosis under appropriate conditions of uncertainty. It is of top importance to give a prognosis of technical economical maximum of life cycle due to the application of CBM/PHM approach, its ability or inability to extract equipment, data, and method.

4. IDENTIFICATION OF THE RISK LEVEL OF TECHNICAL CONDITION OF HIGH POWER TRANSFORMERS

The fourth chapter overviews the methodology of risk level detection of the transformer technical condition. Evaluation of risks allows to judge on the potentially possible faults of the transformer operation and their sequences. Application of this *methodology together with the integrated maintaining approach described before and methods of defects determination gives an opportunity to plan further operation of transformer in accordance with assumed level of risk.*

Detection of risks in the area of transformers exploitation is an aspect of top importance because the transformer defects and their further sequences can be very negative and significantly impact the producer of the electric power and its operator as well as its final consumers. Risk is a complex aspect covering the probability of failures (emergency situations) and the evaluation of its negative sequences. Therefore it is necessary to know the potential risks, short-term and long-term risks. The evaluation of risks is the process of qualitative and quantitative estimation of the risk result on the further exploitation of transformer. Totally the risk is defined as a result of two parameters: probability of the equipment downtime and its sequences. Visually the main steps of risk evaluation can be represented in the following way, fig.4.1. [25].

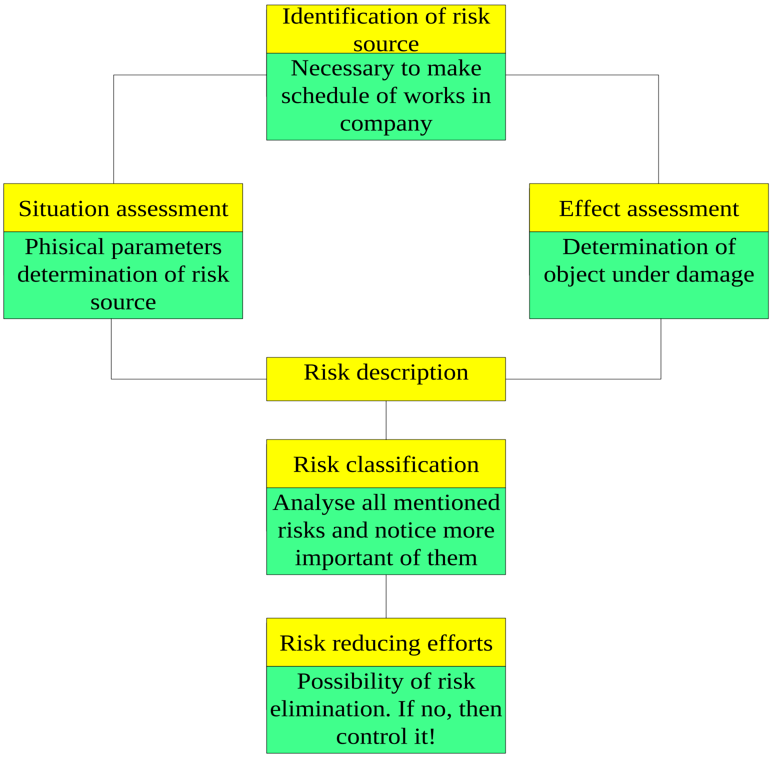


Fig.4.1. Methodology of risk evaluation

The risk evaluation for transformer defects is directly connected with the factor of transformer technical condition (TCI). The higher is TCI the lower are the risks. Classification of risks includes 5 levels. In addition so called risk evaluation matrix is applied for the value of technical condition factor (TCI). The level of risk is defined previously determining the potential sequences of the risk and its possibility, Table 4.1. The sequences and possibilities of the risk are directly connected with TCI value, for example: $80 \leq TCI \leq 106$ and $60 \leq TCI < 80$, then it corresponds to the evaluation of risk as "low dangerous", if in its turn $10 \leq TCI < 60$, then it is „dangerous" and finally, if $TCI < 10$, then it corresponds to the evaluation „very dangerous".

Table 4.1

Qualitative evaluation of risks - determination of the risk level

Possibility of risk	Sequences of risk		
	Low dangerous	Dangerous	Very dangerous
Not possible	INSIGNIFICANT RISK (I)	REASONABLE RISK (II)	TOLERABLE RISK (III)
Less possible	REASONABLE RISK (II)	TOLERABLE RISK (III)	SIGNIFICANT RISK (IV)
Possible	TOLERABLE RISK (III)	SIGNIFICANT RISK (IV)	INADMISSIBLE RISK (V)

During the period of the transformer exploitation applying TBM/CBM maintaining approach the potential threatening risks are evaluated with the assigning it with a correspondent level. Then it is necessary to make a technical decision about the required activities. Therefore the package with preventive measures is developed, Table 4.2.

Table 4.2

Evaluation of the realized package of preventive measures

I level	All the necessary (or possible) measures for the reducing or avoiding of risk factor impact are taken.
II level	The actions for the decreasing of the risk factor impact should be taken in perspective
III level	The measures for reducing or avoiding of the risk impact are mandatory

For the analysis of risk and especially for the estimation of risk probability the designing, production, operation, political and management decision making have the critical significance. The risk analysis is described with the connection downtime probability and its sequences without maintenance expenses, e.g. to avoid downtime the major overhaul or renovation are not taking into account. Therefore the basic idea of full risk analysis approach is to estimate the maintenance expenses and it is also made for the downtime probability and its sequences as well.

MAIN RESULTS AND CONCLUSIONS OF THE RESEARCH

The investigation of the Doctoral work resulted in:

- the improvement of the approach to LR TSO high power transformers exploitation; the approach was obtained:
  - integrating TBM and CBM maintaining methodologies,
  - applying modified calculations for the determining of the transformer technical condition factor,
  - to include the detection of remain lifetime, prognosis of technical condition and evaluation of risk of transformer faults into the maintaining approach;
- optimization of the existing methods of determination of transformers technical condition, a minimum range of the first stage measurements of the optimized diagnostic algorithms is defined;
- additional criteria of technical condition determining are analysed, proposed as well as proved in practice (absorption factor (Kabs) and dielectric losses (tgδ) correlation, detection of the relative weight (level) of transformer group condition);
- the fact is proved that a transformer with life more than 25 years has a linear positive correlation of Kabs and tgδ values. Therefore the modernisation provided during the operation positively influences the total technical condition of the transformers and can be considered as a highly effective activity;
- the complex diagnostic algorithm is completed with rejecting criteria (for example, RIP insulation for cables with C2 measuring scheme (bar+screen), testing of solid insulation at 300 seconds and 5 kV supplied voltage, measurement of mutual winding capacity, screening the rest of those);

The investigations made in the Doctoral work result in the following conclusions:

- the integrated maintaining approach (optimized algorithm) allows safe the invested financial means for the high power transformers park renovation and optimise the amount of disconnections for repair and maintenance;
- the application of the integrated exploitation gives an opportunity for more rational technical economic policy improving in this way the effectiveness of technical maintenance. The application of the integrated maintaining approach allows varying the period of the further transformers inspections that does not exceed the LR TSO assigned restrictions.

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