Research into the current state of accident rate of electric networks in agriculture using the example of Astrakhan region

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Abstract. The paper deals with the accident rate of power electrical equipment of transformer substations of rural electric networks is studied depending on a number of factors, i.e. voltage class, service life, organizational and technical reasons for equipment damage as well as the type of equipment elements. The analysis was carried out on the basis of data for 2019 provided in the annual report of the branch of PJSC “Rosseti South”. In addition, the paper considers the information of patent documents in the subject area "Diagnostics of power electrical equipment" over the period of 2012-2019. The limited possibilities of the known methods for the purposes of operational forecasting of pre-emergency situations are shown. The feasibility of developing an intelligent data and measurement system for substations that supply electricity to remote agricultural facilities that uses complex diagnostic methods and provides operational forecasting of pre-emergency situations of transformer substations is justified.

1. Introduction

Currently, due to the acceleration of advances in science and technology, it is possible to form economical, reliable power supply systems for enterprises, introduce microprocessor technology, gas and vacuum electrical equipment, and new complete converter devices.

One of the examples of electric power system objects that provide electricity to a rural settlement is the substation "Zelenga" in Astrakhan region. It provides power to consumers of all categories and therefore must meet all reliability requirements. In the area of its operation there are consumers of the I⁰, II⁰ and III⁰ categories for the reliability of power supply. The main consumers of electric energy are:

- Residential sector,
- Agricultural complex,
- Tourist recreation centers,
- Private enterprises.

The major concerns in the power supply are:
- The wear of the equipment in Zelenga substation reaches 73%;
The wear of the 10 kV networks leading to the ITS is 96%;
- Wear of 0.4 kV distribution networks reached 88%;
- ITS equipment is extremely worn out (100%);
- There are no autonomous power supply sources;
- Unattended power grids are available.

Meanwhile, in rural areas, there is a tendency to increase the volume of electricity consumption due to the electrification of the population's everyday life, an increase in the number of household appliances, the development of agricultural enterprises and the tourism business, etc. A significant increase in the load is due to tourist bases "Peney", "Cool place", "Development", "Poppies" and agricultural farms "Red Star", "Small Zelenga" etc. Construction of new and restoration of old workshops is planned on farms. The resulting contradiction between the wear and tear of the equipment of the electric power system and the growth of electrical loads makes the task of modernizing substations in rural settlements extremely urgent.

Currently, many substations use worn-out and obsolete equipment, which can lead to failures and loss of electricity for agricultural consumers. It is obvious that the current situation creates a tendency to the occurrence of obvious and hidden equipment failures in the power supply system of consumers.

The problem of power equipment accidents is paid attention in a number of works. Methods for diagnosing emergency conditions and analyzing the state of wear of electrical equipment of substations have already been partially disclosed by us in [1].

The analysis of accidents in the electric networks of 6-110 kV of Kuzbass power system is presented in [2]. The most emergency element of the power system of Kemerovo region is 6-10 kV networks. The consequences of accidents in networks of higher voltage classes are more severe. However, their total number is only about 15 % of the total number of technological violations. Single outages in 6-10 kV networks usually led to less serious consequences. Nevertheless, due to their large amount, the total number of consumers left without electricity as a result of technological violations in 2015 in 6-10 kV networks is almost 3 times higher than the same value for 35-110 kV networks.

An analysis of the accident rate in 0.4 kV electrical networks of Nizhny Novgorod region was carried out in [3]. This article deals with some problems of technological violations and accidents in 2019. More than 1000 technological violations (TV) were detected, which occurred in 0.4 kV networks of Nizhny Novgorod region power system. Distribution of TV by voltage classes is the following: 0.4 kV-72 %; 6-10 kV-27 %; 35-110 kV-1 %. More than half of TV (72 %) was recorded in 0.4 kV networks, and about one third of TV (27 %) occurred in 6-10kV networks.

In [4], accident rate in the power grid complex is analysed. The main causes of technological failures on overhead lines, substation equipment and cable lines are considered. One of the major contributors to technological violations is seen as "Non-compliance with deadlines or non-compliance with maintenance volumes".

In [5], statistical indicators of accident rate are considered, the reasons and prerequisites of technological violations in elements of 6 kV and above electric networks is analyzed.

In [6], the current state of electrical networks, the accident rate and the reasons for disconnecting electrical equipment are examined. Ways to improve the efficiency of distribution networks in the agro-industrial complex are outlined. As for the fleet of power transformers in the agro-industrial complex, it is worn-out and outdated. The share of new transformers does not exceed 7%. Transformer substations of 6...10/0. 4 kV, as a rule, are single-transformer and connected to power lines (PL), mainly according to a dead-end scheme. Only 13% of substations are closed, and 15% of the total number of transformer substations are in unsatisfactory condition.

In [7], the main types of overvoltages, the causes of their occurrence and their impact on the power electrical equipment of electric grid enterprises are studied.

Based on the analysis of the materials presented in [1-7], it can be argued that the problems of accidents of electric networks are multidimensional. Also the causes and types of accidents should be
considered taking into account the voltage class, the type of consumers, the requirements for the reliability of power supply and regional specifics.

2. Materials and methods

In this paper, a study of the accident rate and physical condition of power electrical equipment of transformer substations is proposed, by the case PJSC "Rosseti South" branch object of "Astakhanenergo".

With reference to the program of prospective development of Astrakhan region power industry [8], the actual wear of the power grid complex for substation equipment amounts to 76.03%. According to [9], the level of physical wear of power grid equipment in Astrakhan region is reaching a critical point.

The current paper considers the accident rate of power electrical equipment in transformer substations depending on a number of factors, i.e. voltage class, service life, organizational and technical reasons for equipment damage as well as the type of equipment elements. The analysis was carried out on the basis of data for 2019 provided in the annual report of the branch of PJSC "Rosseti South"[10].

3. Results

The number of step-down transformer substations in the Astrakhan region is the following: 110 kV PS - 91 pcs., 35 kV PS - 43 pcs., 6-10 kV TP and RP - 4138 pcs. The wear of transformer substations is shown in figure 1.

![Figure 1. Wear of transformer substations, 2019.](image)

As the main organizational reasons leading to accidents, we single out the wear and tear of equipment, the impact of extraneous and natural factors, late detection of defects and non-compliance with maintenance. The distribution of accidents according to the main organizational causes is shown in figure 2.

The major causes of damage to the equipment are related to the violation of electrical insulation, violation of electrical contact, external mechanical impact, ingress of foreign objects, mechanical destruction, violation of the structure of the material, corrosion wear, electric arc damage and exhaustion of the resource. The distribution of accidents according to the main technical causes of damaged equipment is shown in figure 3.

Statistics of damage to substation electrical equipment elements for 2019 are shown in figure 4.

The analysis showed that the greatest number of equipment damage occurs in the voltage class 6-10 kV (figure 5).
We found that the largest number of accidents occurred on equipment with a service life of more than 20 years, which is 81.2 % (2.7 % more than in the same period of the last year). Emergency foci and bottlenecks occur primarily due to significant physical wear and tear of electrical network equipment due to excessive service life (figure 6).

As for equipment with a service life of more than 20 years, there are a large number of 6-10 kV power transformers that have worked for one standard period or more (about 70 % of their total number).
Accident prevention requires introduction of diagnostic methods, techniques and systems. In this study, we conducted a patent search in the subject area "Diagnostics of power electrical equipment". As a search and data system, we applied Rospatent database "Russian patents for inventions and utility model patents, applications for inventions, abstracts". Patent research was conducted in accordance with the established rules "Patent research Content and procedure" by GOST [11]. The scope of patent search was adopted from 2012 to 2019 [12]. In the patent search, we used the following classification categories of the International Patent Classification (hereinafter IPC): section G "Physics", section H "Electricity".

When conducting a detailed analysis of patent information, we selected 41 security documents in eleven IPC headings as a source for further consideration. The number of patents for the considered subgroups for the period from 2012 to 2019 is shown in figure 7.

The number of patent documents issued under classification headings is shown in figure 8.

In the inventions considered, various methods of diagnostics of power electrical equipment are used. Figure 9 shows how many inventions are affected by certain methods. The total number of inventions considered was taken as 100%.
The following diagnostic methods are defined:

- Measurement of electrical values,
- Oil diagnostics,
- Thermal methods,
- Method of partial discharge,
- Vibration diagnostics.
Figure 9. Distribution of patents in %, by methods of diagnostics of electrical equipment

4. Discussion
The key reasons for technological failures in the operation of substations are associated with wear and tear of electrical equipment. In addition, the causes of accidents are untimely compliance with equipment maintenance standards and poor quality of their implementation.

The most damaged category is oil-filled equipment. Despite the fact that the age of modern technology is moving away from traditional, oil-filled equipment, but it still remains the core and main one in substations. In addition, it is one of the most expensive, both in purchase and maintenance.

More than 60% of cases of damage occur in the voltage class 6-10 kV. This is worth paying special attention to, because the system has 4,138 transformer substations and RP 6-10/0.4 kV, with a total capacity of 1,147.2 MVA. This equipment is particularly vulnerable to technological disruptions, as the protection systems for such substations are often technically simplified and obsolete.

It is established that the largest number of inventions aimed at the development of methods and means of monitoring systems for diagnostics of power electrical equipment of substations belongs to G01R 31/00 subgroup. Also, a fairly large number of inventions are presented in G01R 31/02 and G01R 31/12 subgroups.

Based on the analysis, it is shown that the most common method of diagnostics of power electrical equipment of transformer substations is the method of measuring electrical values (36.82% of inventions). The second rank is occupied by methods of oil diagnostics (23.7%), the third - by thermal methods (21%). To a lesser extent, partial discharge detection and vibration diagnostics are used.

Limited capacity of the known methods for operational forecasting of pre-crash situations has been identified, namely: methods of electrical measurements. They are typically implemented with a disconnected transformer. Methods of oil diagnostics require oil sampling and analysis in specialized laboratories. Thermal methods are still insufficient for situation assessment and decision making. Vibration diagnostics and monitoring partial discharges are difficult to implement and have a relatively low accuracy.

5. Conclusion
In order to solve all the above problems, reconstruction and technical re-equipment of facilities are necessary. However, since the replacement of power equipment at transformer substations will entail serious economic costs, it will be relevant to install various diagnostic and expert systems for monitoring the condition and operating modes of electrical equipment. Such systems will allow timely detection of pre-emergency situations, which will eventually lead to extension of equipment service life. It will also require less maintenance costs.
At the present stage of digitalization of the electric power industry, it is expedient and becomes possible to develop an intelligent information and measurement system that uses complex diagnostic methods and provides operational forecasting of pre-emergency situations of transformer substations.

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