Analysis of the accident rate and reliability of the city power supply system networks

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Abstract. This article provides an analysis on the subject of reliability indicators and statistics of accidents in urban power supply networks. Based on the analysis, the authors considered the causes of accidents, their probabilistic and statistical indicators, violations of the regulations that contribute to technical violations, as well as the conclusion that the main directions for the further development of this topic are in the plane of identifying unidentified causes of accidents, conducting a simulation experiment, predicting accidents and establishing causal - investigative factors between different aspects of the issue.

Keywords: power supply, accident rate, reliability, failures, statistics.

The problem of accidents and reliability of urban power supply networks in the last 7-8 years has acquired a high degree of relevance. There are several reasons for the increased demand in the development of this issue.

Firstly, this is the economic aspect, the knowledge of which helps to assess the possible costs in case of accidents, to prevent possible failures by dismantling economically disadvantageous and installing economically optimal nodes of the city power supply system (CPSS). As an additional result of the analysis of the accident rate and reliability of CPSS, it is possible to predict the probable damage in monetary terms for the given economic parameters of the urban infrastructure of the power supply system (for example, budget parameters for the repair of CPSS, renewal of cable lines and electrical distribution equipment, re-equipment of control points).

Secondly, infrastructural capital investments and optimization of the material and technical base make it possible to talk about the social and humanitarian aspect of the analysis of the accident rate and reliability of the CPSS. Improving the operating conditions of the CPSS will entail the optimization of occupational health and safety, provided that the extensive approach prevails over the intensive, that is, when financing is relied on not on a quantitative measure of capital investment, but on a qualitative one: intellectualization and automation of equipment, development and motivation of CPSS service personnel, long-term prospects for infrastructure development.

Third, a substantive analysis of the accident rate and reliability of the CPSS will help in the rational use of energy resources. This is the environmental aspect of this issue. For example, in the event of an accident at a traction substation, an energy leak is possible, which leads to an irrational use of electrical energy.

Fourthly, the technical side of this issue allows making small "discoveries" in the causal factors that affect the accident rate and reliability of CPSS. For example, when setting up a modeling experiment, D. Ye. Alekseev establishes significant deviations in the parameters of accident rate and reliability of CPSS, depending on the simultaneity or non-simultaneity of testing of all nodes and devices of the CPSS [1].

Here is a diagram of the main causes of technical failures in the urban power supply systems of the Sakhalin Oblast, according to the data of PJSC "Sakhalinenergo" for the period 2010-2020 (see fig. 1).

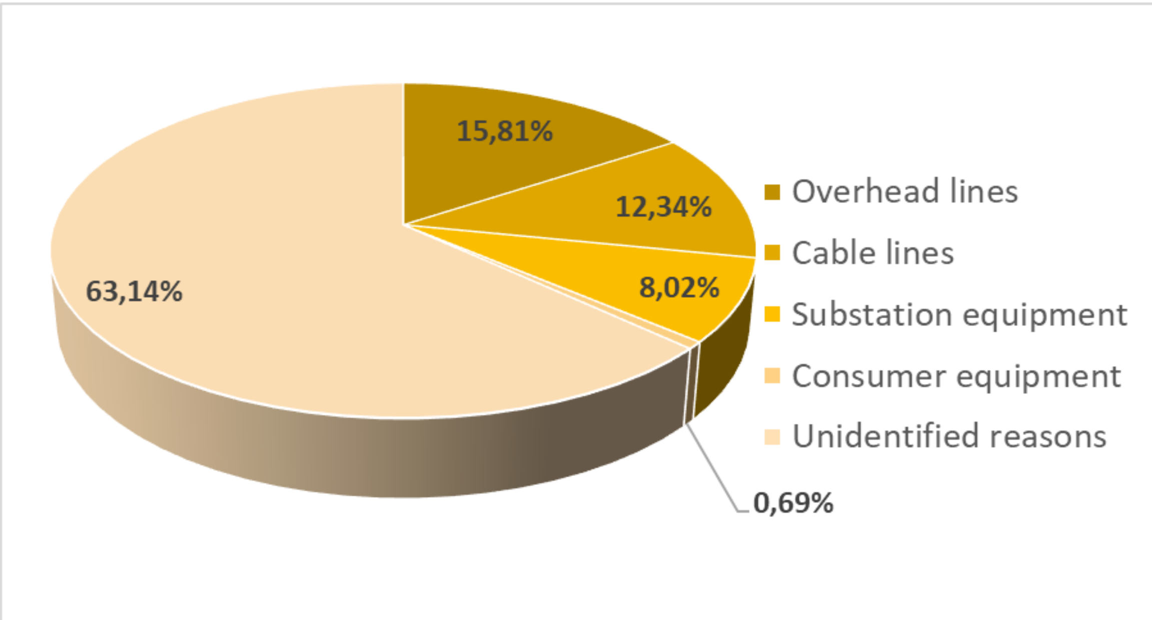

Figure 1 – CPSS accident statistics by type of equipment, in percent

Let's analyze this diagram. The high degree of unidentified causes of technical failures leads to the fact that the degree of data reliability is at the level of 100 - 63.14 = 36.86%. However, this diagram retains the ranking of the causes of accidents. Indeed, overhead lines are the most vulnerable because they are in open space, so they come first. Cable lines are located in the area of construction works, so they are in second place. Substation equipment in comparison with consumer equipment - high-voltage - has a high utilization rate, therefore, they quickly wear out and fail.

The work of T. V. Alferova provides a list of technical violations (TV) of air and cable lines [3]. In a similar way, we will present an overview of such violations for the urban power supply systems of the Sakhalin Oblast, for the same period of 2010-2020 (see fig. 2, 3).

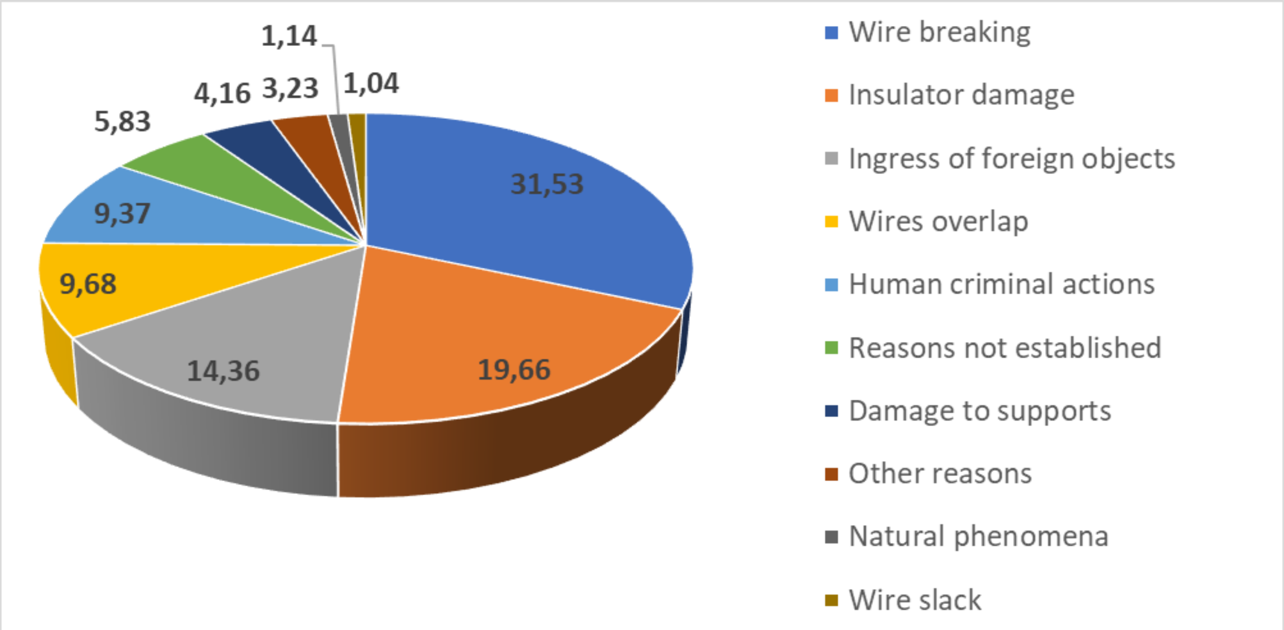

Figure 2 – Distribution of technical violations of overhead lines, in percent

As you can see from this diagram, for overhead power lines, the first place is taken by a break, the second is damage to the insulator, 3 is the ingress of foreign objects (fallen trees during a strong wind, the accidental hit of thrown objects), 4 is a clash of wires, 5 is criminal human actions.

For cable lines, the distribution is different. Here, in the first place, not a cable break, but unidentified reasons. Then, on the 2nd place - insulation breakdown, on 3 - actions of 3 persons, on 4 - damage to the coupling, and only on 5 - cable break (see fig. 3).

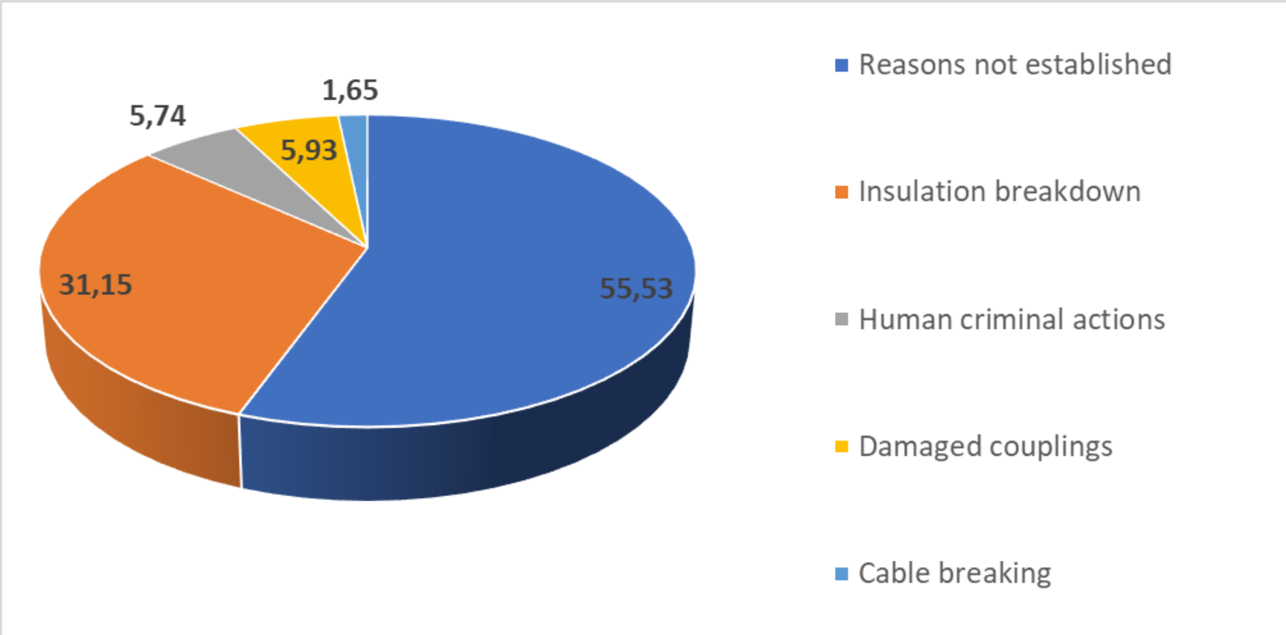

Figure 3 – Distribution of technical violations of overhead lines, in percent

In their article, S. A. Zakharov, D. S. Kudryashov and others deviate from the empirical nature of their research and cite theoretical factors. So, in their opinion, the availability of high-quality equipment and accurate operation does not guarantee 100 percent fault tolerance of electrical equipment [4].

As these authors rightly point out, the contradiction of the situation lies in the objectivity of the reasons and the non-deterministic nature of the refusal. Untimely elimination of this discrepancy leads to a situation of exponential "expansion" of deviation monitoring data during the operational use of CPSS equipment. Further, the authors provide various theoretical estimates of the reliability parameters. The frequency and length of the CPSS are used here as a quantitative measure of reliability indicators.

Unfortunately, such indicators are difficult to statistically process by elementary statistical methods due to the "floating" nature of the time intervals of technical violations and their movement from the independent variable (argument) to the dependent variable.

The quantitative measures of reliability proposed by M. V. Akulov and V. P. Maksimov are the basis for the methodology for assessing economic efficiency in the rational modernization of CPSS [1]. The economic parameters of losses from such undesirable processes in the functioning of CPSS, as disconnecting consumers from power supply, breaks for emergency and counter-emergency repairs, can act as arguments for the function of assessing the reliability of objects and components of CPSS. Having calculated the extrema of this function, it is possible to set criteria for the optimal reliability of power supply in the standards and operating agreements of the service level.

The strategic goal of supplying CPSS is to find an extreme point of the overall CPSS reliability indicator not as a function of annual costs, as well as to meet the cost-benefit criterion for the above processes. The authors cite a trend in the statistics that denoted the uniqueness of device failures in the years following the first failure. This trend is a consequence of the non-determinism of undesirable processes in the functioning of CPSS and a statistically determined low percentage of repetition.

Thus, unscheduled preventive maintenance work on these devices, aimed at preventing an already occurring failure, can only bring extra costs without achieving the ultimate goal of increasing the reliability of CPSS in the next year.

S.G. Zakharenko emphasizes that due to the probabilistic nature of reliability indicators, economic damage can be estimated only within the range with minimum and maximum values. He divides the problems of assessing damage into 2 types: with a known and unknown reliability indicator. The thesis of his research is that the determination of reliability parameters will lead to a narrowing of the range of economic damage [5].

In his work, the author cites general trends typical for CPSS, such as wear at the level of 65-70%, low power-to-weight ratio, and underfunding of the industry since the 90s of the last century.

D. V. Chernov gives formulas for the main indicators of CPSS reliability [6], including PNFO (probability of no-failure operation):

$P(t)=n(t)ln(o)$,

where $n(o)$ – the number of objects observed at the beginning of the experiment;

$n(t)$ – the number of remaining operational objects at time t (non-recoverable objects).

Failure rate in a short period of time t, $t+\Delta t$:

$$\lambda(t) = \frac{n(t) - n(t + \Delta t)}{n(t)\Delta t} \qquad (1)$$

Recovery rate:

$$\lambda(t) = \frac{n(t + \Delta t) - n(t)}{n(t)\Delta t}, \qquad (2)$$

where $n(t + \Delta t)$, $n(t)$ − the number of objects whose restoration lasted less than $t+\Delta t$ and t respectively.

Studies conducted by the Department of Electric Power Industry of Sakhalin State University, using the example of technical violations in the city power supply systems of the municipalities of the Sakhalin Region, allow us to conclude that the main causes of technological violations with damage to equipment are "Failure to meet deadlines or fail to meet the volume of maintenance" (more than 47%) and "Overlapping of insulation as a result of lightning surges" (almost 38%), which is due to severe wear and tear of the equipment.

It should be noted that the control over the effectiveness of measures outlined by the acts of investigation of technological violations to prevent the causes of similar outages is not carried out at the proper level, and the necessary measures to eliminate similar (previously identified) violations at power facilities are not fully planned and implemented.

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