Algorithm for the choice of power supply system rational structure of gas pumping stations

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Abstract. The article provides main unit and complex reliability indicators used to appreciate reliability of power supply systems for gas pumping stations. The main goals of reliability calculation are presented. The methodology for the determination rational structure of the power supply system is given. The algorithm for the choice of rational structure and its main stages are described. Recommendations for determination directions of optimization power supply system structure are given.

1. Introduction
Modern power supply systems have a complex structure with a large number of elements. The reliability of such systems can be one of the criteria for determining their rational structure as well as economic indicators [1,2].

The power supply system can be divided into power part, and part of the relay protection and network automation. The power part provides transmission of electrical energy. The second part protects elements and provides automatic switching in the system [3,4,5].

The power supply system has a large number of consumers of electric energy. These consumers can be classified in various categories according to the reliability and uninterrupted power supply. They are subject to various reliability requirements [6,7]. The calculation of the reliability of power supply should be carried out separately for each group of consumers. In practice, a quantitative description, analysis and assessment of reliability is carried out for the consumers farthest from the power source. The greatest number of system elements is involved in the power supply of such consumers. Power supply reliability of other consumers will be no worse.

2. Initial data and reliability indicators
As the initial data for calculating the power supply reliability we used:
- reference data on the reliability of system elements;
- data on the reliability of similar elements;
- results of processing statistical information on the reliability of similar elements working in similar power supply systems.

The main single indicators of failure-free operation are the mean time between failures of a system MTBF and the probability of failure-free operation $P(t)$ for a certain category of electricity consumers. The main single indicator of maintainability is the mean time to recovery MTTR of power supply to electricity consumers of a certain category. A comprehensive indicator of reliability is the system availability factor. It characterizes the readiness of the system to perform its functions.
Reliability calculation results are compared with standard values of reliability indicators at all stages of power supply systems design. They are established as a result of setting requirements for reliability or standardizing reliability and entered into normative and technical documentation - technical specifications or technical requirements.

3. Reliability calculation goals
The main goals of calculating the reliability of power supply systems are:

- checking compliance of reliability indicators with the requirements of regulatory documents;
- a comparative analysis of the reliability of various system structures and the choice of a rational option;
- justification of options for improving the structure of the power supply system, maintenance and repair;
- assessment of the effectiveness of the proposed options;
- solving various optimization problems in which reliability indicators act as target functions.

4. Substantiation of the power supply system rational structure
The methodology for substantiating the power supply system rational structure includes the following main steps:

1. Justification of indicators to assess the reliability of the power supply system elements.
2. Justification of methods for obtaining the values of calculated reliability indicators of the power supply system elements.
3. The initial formalized formulation of the problem in the form of a structural description of the investigated properties of the power supply system reliability.
4. The construction of a mathematical model for evaluating of power supply system reliability.
5. Modelling and calculating the reliability indicators of power supply systems using special software systems.

At the first stage, it is necessary to substantiate reliability indicators for system elements, as well as reliability indicators for the power supply system itself. When substantiating the indicators, it is necessary to take into account the main differences in the reliability assessment for repairable and non-repairable elements. Also, it is necessary to take into account differences in the reliability analysis of individual elements and systems consisting of functionally connected different elements.

At the second stage, you must consider that the reliability indicators of elements (indivisible parts of the system) can be determined only on an experimental basis, by special tests. The second way is the collection and processing of statistical data on their operation.

The primary formalized model of knowledge about the studied properties of system is created at the third stage. The primary model, as a rule, is not computational. I.e. direct calculations of the numerical values of any systemic properties indicators based on it are not provided.

The fourth stage determines how accurately and reliably the developed mathematical model describes the behavior of the system in terms of reliability. The value and veracity of the results for substantiating the rational structure of the power supply system depend on this.

At this stage, the following activities are carried out sequentially [8]:

- the logical health function (LHF) is built on the basis of the developed functional integrity scheme (FIS) and functioning criteria;
- the probabilistic health function (PHF) is built on LHF basis, using the laws of probability theory.

PHF is essentially a mathematical model of reliability power supply system. The construction of LHF and PHF is a complex and time-consuming task. Therefore, to solve it, specialized software systems are used, for example ARBITR software [9].

The fifth stage is the final stage of the analysis of structurally complex power supply systems and is based on the use of mathematical models to calculate various system characteristics.
The rational structure of power supply systems can be determined on the basis of existing power supply systems in operation, or on the basis of systems being developed (designed). The algorithm for determining the rational structure of the power supply system corresponding to the described method is presented in figure 1.

**Figure 1.** The algorithm for determining the rational structure of the power supply system.
The criterion for optimizing structure of power supply systems should be the minimization of structural elements while providing a system reliability indicator not lower than the requirements of regulatory and technical documents. The implementation of this criterion will provide high values of technical and economic indicators for the creation and operation of power supply systems. In this case, the main goal is to minimize costs (to avoid knowingly unjustified costs) while maintaining the standard values of reliability indicators.

The calculation involves the sequential implementation of the four stages described in detail above (blocks 1 - 4 of the algorithm). If the considered power supply system does not correspond the requirements for a system reliability indicator $P_C$, it is necessary to determine the main directions for improving the structure. And then repeat the entire iteration loop again. The calculation is repeated until the system reliability indicator corresponds the permissible value.

The direction of improving the power supply system structure is determined by the positive $\beta^+$ and negative $\beta^-$ contributions indicators of elements [10]. Changes in the reliability indicator of system and contributions of elements can be caused by changes in the initial probabilistic characteristics of system elements $P_i$. This is possible when replacing structural elements with elements that have better characteristics, as well as improving (optimizing) the system structure.

In the process of determining directions for improving the structure of the power supply system, the following rules should be used:

- any structural changes in the system should not lead to a decrease in the system reliability indicator below the values established by the regulatory and technical documents;
- structural improvement of the system should also be carried out in the direction of aligning the relative values of the positive contributions of the elements (reducing the positive contributions of elements with high values);
- if elements with relatively high positive contributions remain in the system, it is necessary to focus efforts on increasing the reliability characteristics of such elements.

When the directions for improving the system structure are determined, functional diagram of the system is re-developed and the blocks of the algorithm are executed again. After the next iteration, the calculated value of the system reliability indicator is checked for compliance with the requirements of regulatory and technical documents. After that, the power supply system is checked according to the economic criterion (last block of algorithm). In case of discrepancy with the permissible value, measures are developed to reduce economic costs and all stages of the algorithm are repeated again.

5. Example

As an example, figure 2 shows FIS power supply system of compressor station. The optimal structure of the power supply system was established during modelling in accordance with the proposed methodology. This system receives power from its own power plant 10 kV, consisting of 5 gas piston units. One 10 kV power line from an external network is used as a backup source. A 0.4 kV diesel power station is also provided for powering important consumers. Direct current system with rechargeable batteries is used as a backup source for power supply of relay protection and automation devices. This system is responsible the requirements of regulatory documents. If it is necessary to further increase the system reliability index, it is necessary to replace elements with the largest positive contributions.
Figure 2. Functional integrity scheme of compressor station power supply system.

The diagram of positive contributions is shown in Figure 3.

![Diagram of positive contributions](image)

Figure 3. Diagram of positive contributions.

For the considered example, the switch of the 10 kV switchgear and relay protection units located in the 0.4 kV switchgear have the biggest positive contributions.
6. Conclusion
The considered method can be used to determine the rational structure of the power supply system of industrial enterprises at all stages of the life cycle, when designing new systems and reconstructing existing ones. Also, the method can be used with an optimal change in the structure of the power supply system in the event that electricity consumers change their location during operation [11,12]. An example is mining enterprises, which are characterized by movement of the front of work and, accordingly, a change in the location of electricity consumers. The choice of power supply system structure of gas pumping stations can be based on the proposed algorithm. As a result, the structure and numerical composition of power supply sources will be determined. Using the algorithm, an automated system can be built that allows to determine the direction of power supply system structure optimization during design and operation [13].

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