Complex method for restoring the energy facilities technical condition in the Arctic

A Biryukov, E Dobryshkin, Yu Biryukov and N Tokarev
Military Academy of Logistics named Army General A.V. Chrulev, St. Petersburg, Russia

aleks_bir@mail.ru, edobryshkin@mail.ru, uabiryukov@mail.ru

Abstract. The article presents a complex method for ensuring energy security and energy efficiency of energy facilities in the Arctic based on the results of research that allows optimizing the process of design, reconstruction and major repairs of energy facilities in order to reduce heat exchange between building structures and the environment, as well as a number of technical solutions. The use of the developed technical solutions makes it possible to automate the process of building new energy infrastructure facilities in the Arctic and to carry out controlled operation of existing facilities, systems and networks of heat supply in order to prevent their failure.

1. Introduction
The Arctic zone occupies a special place in the national security and effective functioning economic sector system, that's why the problem of heating residential and office buildings takes a special place in the process of developing the Arctic as well as the problem of drinking and technical water supply. However, the high degree of energy facilities deterioration in the Russian Federation, including in the Arctic, is considered as one of the main factors which are hindering the energy park development of the Russian Federation by a number of experts [1], [2], [3], [4], [5]. Significant costs are associated with a number of features of the design, construction and operation of energy facilities in the Arctic, as well as Arctic heating and water supply systems. These features are: increased heat consumption for residential and office buildings heating in accordance with the specific heat characteristic (the amount of 1 m$^3$ heat lost of the building volume (by external measurement) in 1 hour with a difference in internal and external temperature of 10 $\degree$C); increased requirements for the reliability of Arctic life support systems, especially for heat supply systems, the failure of which even for a short period (no more than one hour) leads to defrosting and rupture of pipelines of heating networks, failure of boilers, pumps, heating devices and other heat supply and water supply devices [6], [7], [8].

In this regard, the problem of ensuring energy security and energy efficiency of energy facilities in the Arctic requires a comprehensive scientific approach based on the use of research results and technical solutions that optimize the process of design, reconstruction and major repairs of energy facilities in order to reduce heat transfer between building structures and the environment. The use of these technical solutions allows you to automate the process of building new energy infrastructure in the Arctic and to carry out controlled operation of existing facilities, systems and networks of heat supply in order to prevent their failure [9], [10], [11].

2. Results and discussion
In order to solve this problem, authors developed the comprehensive method, the developed method use allows to restore the energy facilities technical condition in the Arctic, the enlarged block diagram of the author's method is shown in figure 1.

In accordance with the authors’ developed method (figure 1), there are two fundamentally different approaches to the implementation of the process of the energy security of energy facilities improving in the Arctic. Thus, the choice of the energy efficiency criterion as an efficiency criterion entails the centralization of heat generation sources, which requires the lowest fuel and energy resources expenditure.

The choice of the economic efficiency criterion as an efficiency criterion is the decentralization of heat generation sources with an increase in their total estimated cost. However, due to the lack of heat networks, this requires the least amount of capital investment for their construction and operation.

![Figure 1. Enlarged block diagram of the energy facilities life cycle managing in the Arctic](image-url)

Depending on the priority of energy or economic indicators, the decision-maker can decide whether a decision is appropriate or not. Support for making these decisions is possible through the use of the authors’ developed "Program for ensuring military infrastructure facilities energy security", depending on the selected efficiency criterion.

The application of this program allows automating technical and economic calculations for energy security improving within the formation of design options for objects in the Arctic, taking into account their operational content.

Within energy facilities, systems and engineering support networks building, it is often necessary to rent construction equipment, delivery of technological equipment and construction materials to the construction site. So in a market economy, the efficiency improving issue of the transport system for the material resources delivery between the subjects of construction production becomes urgent both in the interests of the developer and in the interests of contractors.

The authors developed the "Device for transporting a residential block-container" (the Russian Federation patent for the utility model RU 189398 U1 dated 21.05.2019) in order to optimize the material resources delivery to the construction and installation works places as well as to unify vehicles, which are intended for building structures delivery to energy facilities under construction in the Arctic. The use of the developed device makes it possible to unify vehicles during construction and installation works and reduce their number with the appropriate replacement of the internal elements of the container block (figure 2).

The proposed technical solution essence is the design change of the container block frame-base by adding elements such as support rollers and eyelets. The technical result of using this container block is a mobility significant increase of these blocks, the reliability increase of their attachment during transportation by using restraints, as well as the use of vehicles with the "multi-lift" system to reduce the volume of loading and unloading operations.
Figure 2. The developed device’ scheme for the container block transporting (designations: 1 - container block, 2 - support frame, 3 - roller, 4 - anchorages, 5 - eyelets).

The Arctic region of Russia is characterized by extreme natural and climatic conditions, that's why construction organizations turn special attention to the implementation of construction and installation works for the construction of energy infrastructure in strict accordance with the schedule, which is approved as a part of the construction organization project.

The authors developed the "automated building complex management system" (the Russian Federation patent for the invention RU 2696064 C1 dated 30.07.2019) in order to control: the performance of works, prevent downtime of construction equipment, vehicles during loading and unloading operations, as well as uninterrupted operation of container blocks during building structures and material resources delivering to the construction sites of energy facilities.

The implementation of this system is carried out through structurally separate services in the contractor organization management apparatus; these services use technical tools of communication, collection, reception, transmission and processing of information, which allows developing of optimal administrative solutions (figure 3).

![Diagram](image)

Figure 3. Schematic diagram of the automated building complex management system: 1 - control room, 2 - radio stations, 3 - building structures supplier, 4 - sites for building structures storing, 5 - energy infrastructure object, 5.i - loaders (i = 1, 2,..., n), 6.j - vehicles (j = L, 2,..., M), 7.i - devices for controlling loaders' operation (l=1, 2,..., L), 8 - information reception and transmission system

The technical result of the developed invention application is increasing the accuracy of determining the loaders' and vehicles' coordinates and speed by suppressing false signals (interference), which are
received through additional channels, and eliminating the phenomenon of "Reverse operation" in GPS signal receivers.

Using of the authors' system improves the monitoring efficiency and ensures the technological processes' compliance and their coordination in time during energy infrastructure' construction through constant monitoring of the building structures' supply and installation on the construction site. Besides, using of the authors' system allows reporting on the works progress through control panel for centralized control of production process and ensuring its resources.

The third phase of the authors’ complex method of energy facilities restoring in the Arctic is carried out by the authors developed a "Method of remote structures diagnostics and device for its implementation" (the Russian Federation patent for the invention 2685578 C1 dated 22.04.2019). Installation of this device and connection to a computer is a process of forming the stress-strain state monitoring complex automated system.

The authors’ developed device allows continuous non-destructive testing, evaluation and forecasting of the structures technical state of energy facilities on the basis of receiving, processing and interpreting information received from the parameter control units (figure 4).

Within the energy facilities' technical condition monitoring by operating organizations, the device registers incoming signals, which are compared with the obtained during certification reference values, and estimates changes in the buildings and structures' dynamic parameters of energy supply facilities based on static characteristics. The developed device provides an efficiency increase of remote monitoring and diagnostics of the energy facilities construction state during the entire period of their operation. The results of technical condition monitoring, which are obtained through the use of the developed technical condition remote monitoring device, are the basis for drawing up an opinion on the current state of energy infrastructure facilities and a forecast for changes in the technical condition for the nearest period.

Condition monitoring of extended objects of the Russian Federation energy park (first of all, heating systems pipelines, boilers, pumps, heaters and other devices of heating and water supply) is possible through the use of authors' developed the "Threaded building elements and structures remote monitoring system" (the Russian Federation patent for the invention 2696668 C1 dated 5.08.2019). The developed system consists of a force-measuring device, a reader, and a control point. Force measuring device allows to carry out control temperature efforts of threaded connections, includes a screwed nut, the washer and the locking element of elastic material. The backing washer is made flat with a diameter smaller than the diameter of the locking element, and the outer diameter of the backing

![Figure 4. Diagram of the remote structures diagnostics device](image-url)

- 1 - controlled section of the structure; 2, 3, 4, 5, 6, 7, 8, 9, 10 – measurement blocks (deformation, mechanical stress, vibration, pressure, slope, air temperature, ground temperature, electric current, electric potential); 11-19 - information converters; 20 - controller; 21 - modem; 22 - radio communication line
washer is larger than the maximum end size of the nut. This device is equipped with a flat force-measuring washer with a diameter equal to the reader diameter and to backing washer diameter with two resonators on the surface acoustic bolts. Load washer made of stainless steel and placed between the backing washers and locking element of elastic material; load washer has two surface acoustic wave resonators. The first resonator is sensitive to the compression load washers through the use of tough connective layer, and the second resonator is sensitive to ambient temperature through the use of soft elastic adhesive (Figure 5).

![Figure 5](image)

**Figure 5.** Force measuring washer (1, 2 – antennas; 3, 4 – connectors; 5, 6 – holes for high-frequency cables; 7, 8 – high-frequency cables; 9 – keyed recess; 10, 11 – resonators, 12 – insulating protective material; 13 – connecting layer; 14 – soft elastic glue).

The system is additionally equipped with a control point in order to expand the capabilities of the existing device and perform remote measurement of force and temperature in various threaded connections of linear energy infrastructure objects. The condition of these linear energy infrastructure objects greatly depends on the probability of failure and the occurrence of an emergency. Developed control point, which interacts with the reader by using complex signals with phase manipulation, contains a computer, a set generator, a phase manipulator, a power amplifier, a duplexer, a transceiver antenna, a high-frequency amplifier, a FMN signals demodulator, the first and second multipliers, a low-pass filter and a narrow-field filter (figure 6).

![Figure 6](image)

**Figure 6.** Remote monitoring system control point of threaded connections: 1 -computer, 2 - master generator, 3 - phase manipulator, 4 - power amplifier, 5 -duplexer, 6 - transceiver antenna, 7 - high-frequency amplifier, 8 - FMN signal demodulator, 9 - first multiplier, 10 - second multiplier, 11 - low-pass filter, 12 -narrow-band filter.

Developed complex method fourth stage realization is a sequence of management decisions on planning repairs and selecting optimal options for restoring energy facilities (figure 5).
Implementation of the alternative design's concept in the formation of design solutions for the construction and restoration (major repairs and reconstruction) of energy infrastructure objects is carried out by using software products, which are developed by the authors and registered in the Federal Institute of industrial property of Russia in accordance with the established procedure. Thus, support for making these decisions, depending on the selected efficiency criterion, is possible through the use of the "Program for ensuring energy security of military infrastructure objects" developed by the authors (Certificate of state registration of the computer program no. 2019615324 dated 24.04.2019). The application of this program allows to automate technical and economic calculations for improving energy security in the design options formation for objects in the Arctic, taking into account their operational content. The developed "program for selecting the repair work type based on the survey and monitoring results of the buildings technical condition" (Certificate of state registration of the computer program no. 2019615148 dated 19.04.2019) is based on the theory of fuzzy sets and fuzzy logic, which allows to determine the most optimal repair work type depending on the variation in the values of moral and physical wear of objects. Authors formed the algorithm and source code of the "Investment distribution program for restoring the buildings" with the aim of increasing automation of calculations, investments planning for the energy facilities restoration in the Arctic (Certificate of state registration of computer program no. 2019614802 dated 15.04.2019). The authors developed the "Program for the consolidated standards formation of annual operating costs for military infrastructure objects" (Certificate of state registration of the computer program no. 2019616131 dated 17.05.2019) and the "Program for planning buildings major repairs in limited investment conditions" (Certificate of state registration of the computer program no. 2019614870 dated 15.04.2019) to select the optimal options for energy facilities restoring with the maximum values of the recovery facilities index in the multiple constraints context by defining operating ongoing and one-off costs.

3. Conclusions

Thus, the Complex method for restoring the energy facilities technical condition in the Arctic is a set of structurally interrelated elements – a scientific and methodological apparatus, the use of which allows for effective management of facilities' construction and technical operation, systems and networks of heat supply in order to prevent their failure.

The use of the developed devices and software products will serve as an additional impetus for the integrated socio-economic development of the Arctic zone, and will also allow significantly reduce the capital investment amount required for the construction and operation of heat and water supply facilities, systems and networks by optimizing decision-making management, automating control and technical condition monitoring of these facilities, systems and networks; improve the quality of energy park facilities.
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