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The use of gas piston installations to increase energy efficiency of industrial enterprises

Guriy A. Kushner[1]✉, Valentin G. Rudakov[2], Svetlana A. Svirina[3]

[1, 3]Astrakhan State Technical University,
Astrakhan, Russia, guriy.kushner@mail.ru✉

[2]Vista, LLC,
Lipetsk, Russia

Abstract. The article presents the results of a study of the potential of gas piston installations for improving the energy efficiency of enterprises. The study applied theoretical and analytical methods to classify energy efficiency measures, evaluate the influence of various factors on the selection of equipment, and analyze the economic effect of using gas piston installations. An analysis of scientific publications and existing experience confirming the feasibility of using these units in industrial enterprises was conducted. A classification of technical measures dedicated to the optimization of electric grids is considered. Proposals for improving the systems of settlement and technical metering of electric power are developed based on an audit of energy consumption and equipment selection. Based on the conducted analysis, a list of tasks for optimizing the modes of electric power systems and power supply systems of industrial facilities was compiled. The choice of including a gas piston power plant in the composition of the enterprise's power supply equipment, allowing for the distribution of energy in both autonomous and parallel modes, is substantiated. The main provisions for calculating the economic effect of the implementation of gas piston installations are presented, demonstrating a significant reduction in electricity costs and an increase in enterprise productivity. This article presents data on the heating system's performance after the reconstruction and technical upgrade of a plant using container-type gas piston installations. The selected gas piston installation provides continuous operation with automatic start and stop, supplying power in parallel with the external grid without distributing power to the external grid. The methods and recommendations proposed in this article can be used by industrial management to make informed management decisions aimed at improving energy efficiency and reducing energy costs. The results will be useful to process engineers, production management specialists, and company executives interested in reducing operating costs and enhancing business sustainability.

Keywords: gas piston installations, power grids optimization, energy efficiency, autonomous power sources

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Научная статья

Применение газопоршневых установок для повышения энергоэффективности промышленных предприятий

Гурий Алексеевич Кушнер[1]✉, Валентин Геннадьевич Рудаков[2], Светлана Алексеевна Свирина[3]

[1, 3]Астраханский государственный технический университет,
Астрахань, Россия, guriy.kushner@mail.ru✉

[2]ООО «Виста»,
Липецк, Россия

Аннотация. В статье приводятся результаты исследования потенциала газопоршневых установок для повышения энергоэффективности предприятий. В ходе исследования применены теоретико-аналитические методы, позволяющие составить классификацию мероприятий по повышению энергоэффективности, оценить влияние различных факторов на выбор оборудования, провести анализ экономического эффекта от применения газопоршневых установок. Проведен анализ научных публикаций и существующего опыта, подтверждающего целесообразность использования этих установок на промышленных предприятиях. Рассмотрена классификация технических мероприятий, посвященных оптимизации электросетей. Разработаны предложения по совершенствованию систем расчетного и технического учета электроэнергии на основе аудита энергопотребления и подбора оборудования. На основе проведенного анализа составлен перечень задач оптимизации режимов электроэнергетических систем и систем электроснабжения промышленных объектов. Обоснован выбор включения газопоршневой электростанции в состав электропитающего оборудования предприятия, позволяющей распределять энергию как в автономном, так и в параллельном режимах. Приведены основные положения расчета экономического эффекта от внедрения газопоршневых установок, показывающего значительное снижение затрат на электроэнергию и повышение производительности предприятия. Представлены сведения о показателях системы отопления после реконструкции и технического перевооружения предприятия с использованием газопоршневых установок контейнерного типа. Выбранный тип газопоршневой установки определяет непрерывный режим работы с автоматическим запуском и остановкой, подающий электропитание параллельно с внешней сетью без выдачи мощности во внешнюю сеть. Предложенные в статье методы и рекомендации могут использоваться руководством промышленных предприятий для принятия обоснованных управленческих решений, направленных на повышение энергоэффективности и уменьшение расходов на энергоресурсы. Выводы будут полезны инженерам-технологам, специалистам по управлению производством и руководителям компаний, заинтересованным в снижении операционных затрат и повышении устойчивости бизнеса.

Ключевые слова: газопоршневые установки, оптимизация электросетей, энергоэффективность, автономные источники энергии

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Introduction

The modern economy places high demands on the energy efficiency of industrial facilities, striving to minimize energy costs and improve production competitiveness. One effective way to address this challenge is to implement innovative technological solutions, such as gas piston installations, which can significantly reduce energy consumption and improve the sustainability of the production process. This article aims to study the potential and specific features of using gas piston installations in enterprises to improve their energy efficiency. The objectives include analyzing methods for optimizing energy consumption, examining existing approaches to energy conservation, and identifying key success factors for implementing gas piston installations.

Classification of methods for improving energy efficiency of industrial enterprises

Improving energy efficiency is typically achieved by optimizing the operating modes of the electric power system. This optimization approach can only be addressed comprehensively, across all stages and hierarchical levels of the system. All measures are divided into three groups [1]:

1) organizational;
2) technical;
3) measures to improve electricity metering and accounting systems.

Organizational measures are the least expensive and focus on optimizing the use of operating equipment. Technical measures are aimed at modernizing and reconstructing existing networks and are associated with significant economic investment. Improving electricity metering and accounting systems indirectly leads to cost reductions and a reduction in losses.

Regime measures include:

1) optimization of voltage regulation laws in the feeder centers of open power grids;
2) optimization of the steady-state modes of closed power grids in terms of reactive power and transformation ratios;
3) optimization of the voltage level of power sources in the grid;
4) switching generators to synchronous compensator operation in the event of a reactive power deficit;
5) optimization of disconnection points for 110 kV and higher power grid circuits with multiple nominal voltages;
6) optimization of disconnection points for 6-35 kV power grids with dual power supply;
7) optimal connection of transformers at substations in low-load mode (disconnection of some transformers, economical operating modes of transformers);
8) alignment of the grid load curve;
9) load balancing of the phases of low-voltage grids. Technical measures include measures for the reconstruction, modernization, and construction of power grids.

Most of these involve the installation of additional equipment and are anticipated during the electrical grid design phase. A model of the technical measures is shown in Fig. 1.

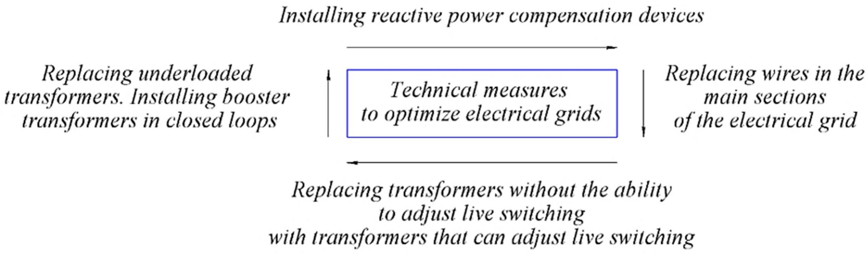

Fig. 1. Model of technical measures for power grids optimization

Improving systems for calculating and technical accounting of electricity

The primary and most promising solutions to the problem of reducing commercial electricity losses include the development, creation, and widespread use of automated electricity monitoring and metering systems, including for residential consumers, tight integration of these systems with the software and hardware of automated dispatch control systems, equipping such systems with reliable communication and data transmission channels, and metrological certification.

Today, the main measures for improving electricity metering systems include:

1) conducting raids to identify unaccounted electricity;

2) improving the system for collecting meter readings;

3) ensuring regulatory operating conditions for metering devices;

4) replacing, upgrading, and installing missing metering devices.

Summarizing the information obtained from studies [2–4], it can be stated that the selection of electrical equipment for an enterprise or municipal facility for the purpose of energy conservation is a process that requires a comprehensive approach.

The following are the main recommendations.

1. Audit and analyze energy consumption. It is necessary to collect information on the enterprise's current energy consumption: electricity bills, meter data, and load charts. Analyze the collected information to identify the main energy consumers, identify peak loads, and then evaluate the efficiency of equipment use. Based on the audit results, it is possible to formulate a specific goal (e. g. a percentage) for reducing energy consumption.

2. Select energy-efficient equipment. For an industrial enterprise, the primary focus should be on the selection of electric motors, frequency converters, lighting sources and their control systems, transformers, cooling and ventilation systems, compressors, and pumps. It is recommended to select electric motors based on their energy efficiency class: IE3 (Premium Efficiency) or IE4 (Super Premium Efficiency). These motors consume significantly less energy than motors of lower classes (IE1, IE2).

Frequency converters are recommended for adjusting motor speed according to demand, which significantly reduces energy consumption, especially for pumps, fans, and compressors. They are indispensable for equipment with variable loads. Sizing is also important. It is recommended to select motors with the optimal power for specific tasks. An overly powerful motor operating under a light load will be inefficient. Lighting requirements during modernization primarily revolve around the installation of energy-efficient LED luminaires. Outdated incandescent, fluorescent, and halogen lamps are replaced. According to technical specifications, modern LED luminaires consume 70-80% less energy and have a significantly longer service life. Additionally, lighting control systems can be installed, including motion sensors, light sensors, timers, and dimmers, to automatically adjust lighting based on occupancy and natural light levels.

When selecting transformers, low losses in the iron and windings are the determining factor. These devices are more expensive, but they pay for themselves through reduced energy losses. Optimizing the transformer load during operation is also crucial. It is recommended to avoid operating transformers with low loads (less than 40%) by redistributing the load or using transformers with lower power.

Cooling and ventilation systems for large production areas should be selected for energy efficiency. Equipment with a high energy efficiency ratio (EER) or seasonal energy efficiency ratio (SEER) is considered preferable. Additionally, automated control systems can be used to optimize the operation of cooling and ventilation systems based on temperature, humidity, and occupancy. Recommendations also include the selection of additional equipment, such as compressors, compressed air systems, and pumps.

The main criteria for selecting equipment for energy efficiency are:

1) technical specifications: determine compliance with process requirements;

2) energy efficiency: efficiency, power factor, and standby power consumption can be quantified;

3) reliability and durability: determined by both actual reliability indicators and indirectly confirmed by equipment operating experience, the manufacturer's reputation, warranty period, and service life;

4) equipment cost, start-up and commissioning costs, ongoing maintenance, and post-warranty support, as well as payback period;

5) compliance with international and national energy efficiency standards.

Optimization of operating modes of electrical energy distribution systems

The trend toward developing methods for optimizing the operating modes of electricity distribution systems based on principles of energy conservation and energy efficiency is driven by the rapidly increasing demand for power from consumers. This is largely due to the increasing complexity of production processes.

Among the first scientists to address the issue of a modern approach to optimizing electrical energy were A. P. Golovanov, V. S. Khachatryan, and M. A. Balabekyan [5, 6]. The authors examined the problems of determining optimal operating modes for energy systems. When discussing the need to define the key criteria for optimal system operation, it is important to begin with the issue of minimizing energy costs for power plants. Additionally, the issue of minimizing and taking into account maximum permissible emissions of harmful substances into the atmosphere and the overall environmental friendliness of electricity generation cannot be overlooked.

The trend toward rising electricity costs and tariffs is driven by the division of the unified energy system into separate components, which has contributed to a shortage of active power. This process has particularly impacted the energy system since the mid-1990s, which has also contributed to the development of new approaches to solving optimization problems.

The choice of an energy system management method-a rational composition of elements or a control method-allows for achieving economic efficiency while simultaneously meeting required conditions. These issues are simultaneously addressed in practice by selecting a rational mode [7–10].

The influence of the wholesale electricity market factor began to be considered in scientific works on energy efficiency and energy conservation with the enactment of Federal Law No. 261-FZ of October 23, 2009, “On Energy Conservation and Improving Energy Efficiency and Amending Certain Legislative Acts of the Russian Federation” [11].

The analysis of scientific publications also revealed that some works are devoted to the problem of formulating a rational strategy for energy system development. For example, work [12] examines the development and justification of the fundamentals of a methodology for analyzing energy systems and determining their development strategy. The use of fuzzy sets in the methodology allows for the accounting of uncertainties in some of the initial information.

A. I. Fedotov's work is devoted to optimizing energy consumption. Work [13] examines a chemical industry enterprise and proposes measures to improve its energy efficiency. It is also worth noting that the work describes the technological features of the enterprise that directly impact energy efficiency. Work [14] proposes a method for optimal energy consumption for an industrial enterprise.

The main criteria for optimizing power system operation modes are economic efficiency, operating costs, active power or energy losses, reliability, and the cost-effectiveness of power supply to consumers. Economic efficiency implies establishing the optimal and most economical operating mode for the system. In this case, the indicator of reduced costs is chosen as the optimization criterion for quantitative assessment. The optimal operating mode of the system must satisfy reliability conditions and comply with power quality indicators, while simultaneously minimizing energy costs at each point in time under consumer load.

Operating costs are comprised of several components: the cost of energy, the cost of lost revenue in the event of a power outage, and the cost of spare parts and equipment repairs.

The active power loss criterion is used when optimizing the electrical grid operation. In this case, the power plant operation modes remain unchanged. The choice of reliability criterion is determined by regulatory requirements, feasibility, and consumer demands.

Minimizing and reducing costs helps to improve the efficiency criterion for power supply to consumers. The primary measures for reducing costs are minimizing the specific fuel consumption for energy production, reducing energy consumption for the enterprise and power plant's own needs, and reducing the specific energy consumption in the form of transmission losses through networks.

An analysis of works [12–15] devoted to defining optimal control problems for systems, enterprises, industrial facilities, and municipal facilities allows us to propose a systematization of traditional problems related to optimizing the operating modes of electric power systems. A classification by degree of importance is shown in Fig. 2.

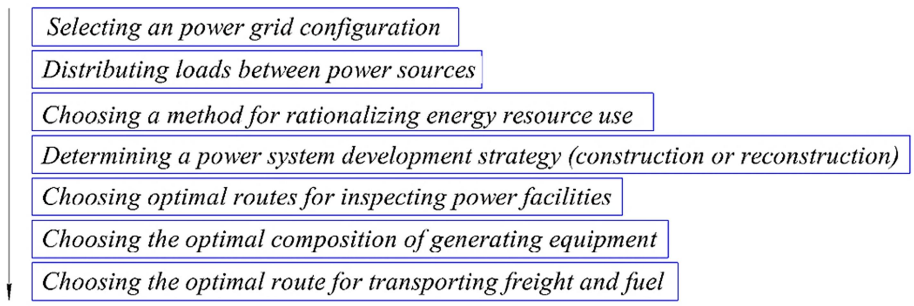

Fig. 2. Model of technical measures for power grids optimization

Use of gas piston installations in the energy supply of enterprises

Using a decentralized approach to electricity generation at industrial facilities is a relevant and in-demand method for optimizing power system operation and directly impacts its reliability. The integration of a gas piston power plant into an enterprise's supply system allows for energy distribution across the power system in both standalone and parallel modes. In the first case, the system is independent and does not require connection to external grids. The second option is more reliable, as the enterprise's energy is supplied both from external grids and generated internally.

Compared to other thermal power plants, gas piston power plants offer high efficiency, low emissions, and are reliable in operation, capable of operating for extended periods at partial loads without deterioration or loss of efficiency. Their use also offers a number of advantages over centralized power supply.

The primary advantage lies in the more efficient use of the combustion products of natural gaseous raw materials – heat. When generating energy in gas piston installations, heat is released through exhaust gas emissions, engine cooling, and oil system cooling. The inclusion of specialized heat exchangers and waste heat boiler units in the heating circuit allows for the heat to be redirected to the enterprise's heating network.

Modern manufacturers of decentralized power generation units employ two approaches to organizing gas piston installation operation at the enterprise: stationary and modular. In a stationary configuration, all system components are installed indoors and are not intended for outdoor operation. The modular configuration allows for the gas piston installation to be housed in a small, free-standing modular container outdoors.

The modular design is preferred in most cases due to the following advantages. Unlike a stationary design, the modular design requires minimal time for commissioning. The use of standardized solutions during module assembly significantly reduces project costs. Additional manufacturing and connection of new modules allows for a rapid increase in the power plant's capacity during modernization or production volume growth. The use of a modular container design reduces transportation costs and ensures the mobility of the entire plant should it need to be relocated.

This article examines the key system indicators using the example of a completed project to reconstruct the heating system and technically upgrade a plant with a 2.3 MW gas piston installation.

The primary equipment of the thermal power plant installed during the technical re-equipment are two TCG 3020V20 gas piston installations manufactured by MWM (Germany), with an electrical capacity of 2 300 kW each. The total electrical capacity of the thermal power plant is 4,600 kW with a voltage of 6.3 kV, 50 Hz, the total thermal capacity is 4.5 MW (3.87 Gcal) at a temperature schedule of 90/70 °C. The primary fuel for the thermal power plant is main gas with a calorific value Qrn equal to 8 000 kcal/Nm^3. Backup fuel is not provided. The primary operating mode of the thermal power plant is operation in parallel with the external electrical grid without delivering power to the power supply organization. In this operating mode, the machine load changes depending on the power consumed by the enterprise.

To prevent power spillover to the external grid, 30 to 50 kW is continuously drawn from it, and the amount of power consumed can be set via the dispatcher's automated workstation. The gas piston installation is designed to automatically switch to island mode if the external grid is lost, and to resynchronize with the external grid when it is restored, without interrupting power supply to consumers. A completely independent operation mode for the thermal power plant, with startup in the absence of the external grid, is not envisaged.

The gas consumption of a single 2 300 kW gas piston installation at 100% load is 541 nm^3/h with a calorific value Qrn of 8 000 kcal/nm^3. With electrical load fluctuations ranging from 40 to 100% of the nominal value, the gas piston installations gas consumption varies linearly from 225 to 541 nm^3/h.

The minimum gas consumption of a gas piston installations is 225 nm^3/h (the unit operates at 40% load). The maximum gas consumption at the thermal power plant is 1 082 nm^3/h (when two gas piston installations operate at full capacity).

The thermal power plant uses natural gas as fuel, which is flammable when mixed with air. Therefore, the thermal power plant is classified as a hazardous industrial facility. The gas supply pipeline for the 2 300 kW gas piston installation is under pressure of 0.01 MPa from the gas pressure control station to the gas piston installation and is classified as hazard class III. Since the amount of natural gas stored at the thermal power plant at any one time is less than 20 tons, it is classified as hazard class IV. The thermal power plant is not designed to use any other fuel.

The gas piston installation operates continuously with automatic start and stop. This type of gas piston installation is an autonomous power source with the ability to operate in parallel with the power grid. The thermal power plant comprises two such units. The gas piston installation is supplied in a fully factory-assembled container. The container includes a ventilation system, gas supply, oil supply, heat recovery system for the cylinder block cooling jacket, exhaust gas cooling, and an exhaust system (Fig. 3).

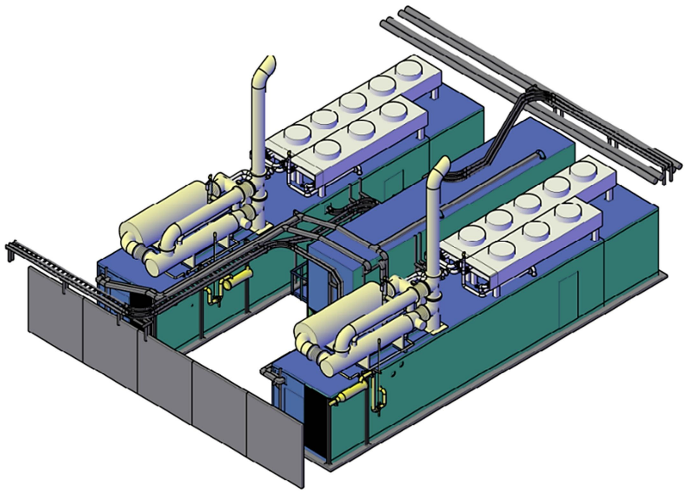

Fig. 3. Placement of two gas piston installations blocks as part of the enterprise's thermal power plant

Gas piston installation control systems include alarms and other means to warn of malfunctions in machinery and equipment that could lead to hazardous situations. Initial synchronization of the generator with the external grid is performed at the generator bay, located in the 6 kV switchgear near the gas piston installation container. The generator bay is controlled during initial synchronization by the gas piston installation control panel, located in the gas piston installation container. The relay start-up unit in the generator bay protects the line between the bay and the generator, as well as the generator itself. Generated electricity is metered by electricity meters located both in the generator bays and in the input bays of the 6 kV switchgear.

Conclusion

The conducted research demonstrates that the comprehensive implementation of gas piston installations can be an effective way to improve the energy efficiency of industrial enterprises. The key requirement is the preparation and informed selection of equipment tailored to the specific needs of a particular production facility. By applying the recommendations presented in this article, industrial facilities can achieve significant reductions in energy costs and increase their competitiveness in the market.

Research Results:

1. Based on the data analyzed, a list of measures for optimizing electrical networks has been substantiated and presented. General recommendations have been developed for selecting electrical equipment for an enterprise or municipal facility to achieve energy savings, a process requiring a comprehensive approach. Key criteria for selecting equipment from a perspective of energy efficiency have been identified.

2. The problem of optimizing energy system operating modes is considered. An analysis of key publications devoted to improving energy transmission and consumption is conducted. The key criteria for optimizing energy system operating modes are identified. A generalized classification of traditional problems of optimizing energy system operating modes is presented. Conducting research and development work to improve the efficiency of power systems will enhance economic efficiency while maintaining the required level of operational reliability.

3. The features of autonomous and parallel operating modes are discussed. Information is provided on the main advantages of using gas piston power plants for industrial facilities. The results of calculating the indicators for a heating system reconstruction project and the technical refurbishment of an enterprise with the installation of a gas piston installation plant are presented.

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Information about the authors / Информация об авторах

Guriy A. Kushner – Candidate of Technical Sciences, Assistant Professor; Head of the Department of Ship Electrical Equipment and Ship Automation; Astrakhan State Technical University; guriy.kushner@mail.ru

Valentin G. Rudakov – Director; Vista, LLC; elmech@astu.ru

Svetlana A. Svirina – Candidate of Technical Sciences; Assistant Professor of the Department of Technological Machines and Equipment; Astrakhan State Technical University; svetlanasv97@yandex.ru

Гурий Алексеевич Кушнер – кандидат технических наук, доцент; заведующий кафедрой электрооборудования и автоматики судов; Астраханский государственный технический университет; guriy.kushner@mail.ru

Валентин Геннадьевич Рудаков – директор; ООО «Виста»; elmech@astu.ru

Светлана Алексеевна Свирина – кандидат технических наук; доцент кафедры технологических машин и оборудования; Астраханский государственный технический университет; svetlanasv97@yandex.ru