Czech Technical University in Prague

Faculty of Electrical Engineering

Department of Economics, Management and Humanities

Economic Evaluation of Centralized and Autonomous Power Supply Systems in Oil and Gas Industry

Master Thesis

Study program: Electrical Engineering, Power Engineering and Management

Field of study: Economy and Management of Power Engineering

Scientific adviser: Ing. Martin Beneš, Ph.D.

Bc. Vadim Ershov

Prague 2017

ZADÁNÍ DIPLOMOVÉ PRÁCE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

Příjmení: **Ershov** Jméno: **Vadim** Osobní číslo: **466084**

Fakulta/ústav: **Fakulta elektrotechnická**

Zadávající katedra/ústav: **Katedra ekonomiky, manažerství a humanitních věd**

Studijní program: **Elektrotechnika, energetika a management**

Studijní obor: **Ekonomika a řízení energetiky**

II. ÚDAJE K DIPLOMOVÉ PRÁCI

Název diplomové práce:

Economic evaluation of centralized and autonomous power supply systems in oil and gas industry

Název diplomové práce anglicky:

Economic evaluation of centralized and autonomous power supply systems in oil and gas industry

Pokyny pro vypracování:

- analysis of power supply systems in oil and gas industry
- centralized and autonomous power supply variants and technical calculations
- economic data evaluation, financial criteria calculation
- sensitivity analysis and decision-making conclusion

Seznam doporučené literatury:

Abramovich B.: Energosberezhenie neftegasovykh predprijatij: uchebnoe posobie. Oil and gas industries power supply. Study guide. Saint-Petersburg: SPb, 2008.
Klimova G.: Energosberezhenie na promishlennyh predprijatijah: Uchebnoe posobie. Energy efficiency of manufacturing enterprises. Study guide. Tomsk: TPU, 2014.
Brealey R. A., Myers S. C., Marcus A. J.: Fundamentals of corporate finance. New York: McGraw-Hill/Irwin, 2012.

Jméno a pracoviště vedoucí(ho) diplomové práce:

Ing. Martin Beneš Ph.D., katedra ekonomiky, manažerství a humanitních věd FEL

Jméno a pracoviště druhé(ho) vedoucí(ho) nebo konzultanta(ky) diplomové práce:

Datum zadání diplomové práce: **17.02.2017** Termín odevzdání diplomové práce: ____________

Platnost zadání diplomové práce: ____________

Podpis vedoucí(ho) práce | Podpis vedoucí(ho) ústavu/katedry | Podpis děkana(ky)

III. PŘEVZETÍ ZADÁNÍ

Diplomant bere na vědomí, že je povinen vypracovat diplomovou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací. Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v diplomové práci.

Datum převzetí zadání | Podpis studenta

© ČVUT v Praze, Design: ČVUT v Praze, VIC

Declaration:

I hereby declare that this master's thesis is the product of my own independent work and that I have clearly stated all information sources used in the thesis according to Methodology Instruction No. 1/2009 – "On maintaining ethical principles when working on a university final project, CTU in Prague".

Date Signature

Abstract

The thesis considers the technical - economic evaluation of centralized and autonomous power supply systems in oil and gas industry. Autonomous power supply system has been implemented for power system optimization and associated petroleum gas utilization. The article investigates the technic of choosing the feeder line, main step-down substation, gas turbine installations for electricity generating. Moreover, it provides explanation of economic model main parameters as investment value, maintenance and total overhaul costs of installed equipment. The new implemented power supply system has been compared with centralized system using economic criteria: net present value, minimum price for electricity in both variants. Sensitivity analysis has been performed on model inputs, which have the most crucial impact to change in NPV: investment value, discount rate, electricity price, external financing share, associated petroleum gas burning penalties.

Keywords

Power supply, oil and gas industry, associated petroleum gas, centralized and autonomous power systems, financial criteria, sensitivity analysis.

Contents

List of abbreviations

APG – associated petroleum gas;

AS – aluminum/steel overhead lines;

bcm – billion cubic metres;

CF – cash flow;

CPF – crude processing facility;

DSG – dry stripped gas;

EAT – earnings after tax;

EBT – earnings before tax;

ELC – electric loads center;

GTG – gas turbine generator;

HRSG – heat recovery steam generator;

HVTL – high voltage transmission line;

MGPS – modular group pumping station;

MSS – main step-down substation;

MW – megawatt;

MWh – megawatt hour;

NPV – net present value;

PTL – power transmission line;

PVAF – present value annuity factor;

SEM – submersible electric motor;

SO UPS – The System Operator of the Unified Power System;

TW – terawatt;

TWh – terawatt hour;

UES – Unified Energy System;

WACC - weighted average cost of capital.

Introduction

The problem of integration in the use of natural resources, including power resources, is the urgent issue for country economy in the context of sustainable development. This issue is applied fully to economy sector of energy resources, wherein the hydrocarbons production industries engross the dominating role.

Oil and gas large overall production level is accompanied by their irrational utilization, when production enterprises pay attention only to salable product or marketable output, while secondary output, associated petroleum gas in particular, has been using ineffectively. Inefficient subsoil use, in the process of oil production, is conditioned upon organizational and technological production processes obsolescence and economic analysis imperfection. Considering that the power supply system is an important part of oil field development and operation process, it exerts a significant impact on energy and economic performance of industry. Therefore, the relevant objective is to improve the power supply system efficiency from an economic point of view.

Insufficient extent of associated petroleum gas utilization was caused by lack of the tough regulating mechanisms, and insignificant penalties for environmental pollution. The required level of petroleum gas utilization gains 95 % according to the government regulations of the Government of the Russian Federation[1]. Since 2014, increase in penalties for above-standard combustion of associated petroleum gas forces oil and gas companies to manage utilization more carefully. Moreover, the increase of coefficient for burning more than five present of mined associated petroleum gas will be equal to 25 by 2020. Some domestic oil companies have already reached required indicator on certain fields, but on the majority of oil fields, the matter is resolved not completely. One of the ways for solving the issue is associated petroleum gas utilization for electrical energy production in oil field.

According to aforementioned, the autonomous power supply system has to be implemented for power system optimization and associated petroleum gas utilization, in comparison with centralized electricity supply system. This way of associated petroleum gas utilization factor increase can simultaneously solve at least two issues: high penalties for pollutions and power supply of industry with high reliability and energy self-sufficiency.

[1] No. 7 of January 8, 2009 "About measures for stimulation of reducing pollution of atmospheric air products of associated petroleum gas combustion on flare installations".

1. Analysis of power supply systems in oil and gas industry

In Russia, it has historically been a tendency to use a centralized power supply for the oil and gas industry. At the same time, long length power transmission lines (PTL) are require to be installed for remote oilfield electricity power supplying. In this case, power supply quality and reliability would be less, especially in harsh climatic conditions. Equipment depreciation in many industries exceed 50-60%, which leads to malfunction and violation of consumer electricity supply systems. [1, 15]

Moreover, there was a deterioration of cost and quality indicators of the Unified Energy System (UES): more frequent cases of sudden interruption in power supply system, equipment aging, electricity tariffs increase, power transmission building costs increase. [15]

Operated oil fields depletion forced to shift production in remote, difficult to access areas. Therefore, the new build objects of oil production are located in the regions of the Far North and Eastern Siberia where there is no centralized power supply that enforce to apply various types of autonomous power sources. The oil and gas industry is distinguished by high energy intensity. Costs for energy carriers in product cost for all vertical of the oil industry quite often constitute over 50 percent.

The modern electric equipment, which ensure oil and gas fields functioning, is characterized by raised quality requirements to the electric power itself and power supply uninterrupted operation. Researches of input voltage deviations influence on a constant operating mode of the submersible electric motors (SEM) (used in electric centrifugal type pumps installations) have shown that undervoltage up to the value of 0,6 from nominal value (more than 0,15 seconds duration) leads to loss of SEM stability and its subsequent stop. Emergency stops and repeated turning on of the pump equipment negatively affect the general resource of its work. In some cases, uncontrollable start-up leads to breakage of the equipment. Furthermore, in the conditions of Far North, continuous operation of the oil-field equipment is necessary for successful course of all production method, even in case of short-term interruptions of power supply, for example freezing of various pipelines used for transfer of oil, water, condensate. Emergency recovery work carrying out often is impossible because of oil-fields majority remoteness from the main energy center and existence only of air traffic or the winter road. Due to the gradual shift of oil production from traditional areas in undeveloped, such as region of the Far North and Eastern Siberia, having no access to the centralized network, autonomous power supply system is the only way of ensuring functioning of an object. [1, 15]

One of the main objectives of the distributed generation is increase in efficiency local energy resources using by means of cogeneration and a trigeneration, and also reduction of a consumption of the oil products. In addition, autonomous power supply development of domestic oil and gas companies is promoted by modern problems of centralized energy networks: high quotations of connection to the network, the limited possibilities of traditional sources, dangers of production processes continuity violation because of possible power supply interruptions. [15]

Figure 1.1. Power supply systems in Russia [11]

Powerful energy systems of oil and gas industries have to be developed in order to ensure power supply reliability. As I have said before, the difficulty of establishing such energy bases is often constituting as considerable distance from oil fields to energy centers. Therefore, designed power system should keep power reserve to provide energy consumption growth without radical reconstruction of the power supply system. The reason for energy consumption growth is mainly explained as new oil production capacity commissioning usually in remote areas with difficult landscape and climatic conditions, which are not developed in order of network infrastructure. Furthermore, designed power supply system should provide electricity in a post-emergency mode, repair mode in accordance with equipment power supply reliability category. [1, 3]

Requirements for the security of electricity supply are one of the important aspects of the oil fields power supply. There are three categories of power supply reliability.

The first category of power supply reliability

The first group of consumers of electrical energy includes equipment, in which the power supply interruption may lead to dire consequences: danger to life, financial and physical damage, plant and equipment damage, mass spoilage of production, failure in complex technological process, community facilities operational stop. The special group within the first group contains equipment, which is essentially needed for prevention of emergencies, hazards and deflagrations.

The first group of reliability requires power supply by two independent, interredundant power sources. Interruption in power supply is limited by time of automatic standby activation. For the special group, the third source is needed (accumulators, local diesel generator).

The second category of power supply reliability

The second group is comprised of equipment, in which the power supply interruption may lead to delay of strategic production, human resources and machinery demurrage, normal human life violation.

It should be supplied by two independent sources and interruption delay is limited by time of manual switching to standby source.

The third category of power supply reliability

The third category of power supply reliability consists of those electrical energy consumers, which are not included in second and third categories. They are supplied by one power source with possible interruption limited by twenty four hours. [8]

Krapivinskoe oil-field, object being examined in the thesis, as oil and gas production plant, typically includes electricity consumers of first and second categories of power supply reliability. In hazardous areas there are types of equipment included in special group of the first category; any case of power interruption is unacceptable for such type of equipment.

1.1 Autonomous electric power stations for oil and gas industry

As I mentioned, oil and gas industry electric power supply could be performed by centralized power network or autonomous local power station. It should be noted that electricity cost share increase, in the total production cost, forces industrial enterprises to look for new options for factory power and heat supply. At the same time, there is no centralized power supply system for many of oil field regions. Overhead lines construction for such areas requires considerable amount of time and most often, it is economically unviable due to huge amount of capital costs. Rising electricity tariffs also increase the share of energy costs in oil and gas companies' budget. In this regard, virtually all oil and gas companies realized energy saving and energy efficiency programs over a number of years. Companies are constantly expanding energy efficient technologies arsenal.

The mining significant energy savings connected with the utilization of associated petroleum gas (APG) with the aim to generate its own electricity, as well as the rejected heat utilization (cogeneration). For this purpose, autonomous power supply systems based on gas piston and gas turbine power plants have been widely developed. In addition, diesel power plants are widely used in remote districts. Experience has shown that the most advantageous solutions are quick-mounting block-modular power stations based on container type constructions with output capacity up to 50 MW. [1, 3, 6]

There are the most important reasons, which motivate companies to make a decision on the construction of their own autonomous energy sources:

- Electricity cost from autonomous energy sources (especially those running on natural gas or associated gas) is significantly lower than the cost of purchased electricity from the national grid;
- Autonomous power stations construction cost for many enterprises is commensurate with the cost of financial loss caused by a power interruption with duration of more than 2 hours;
- Autonomous power plant reliability can be considerably higher;
- Autonomous energy sources existence enables enterprises to provide energy sovereignty, and as a consequence - economic independence from the electricity market. [1, 6]

As the [4] shows, electric energy produced on gas-fired power plants is on the 2d place in the world with 4993 TWh value. Energy produced from oil contain 1068 TWh of total production. Following paragraphs provide information about the most common autonomous power stations used in oil and gas industry.

1.2 Diesel power stations

Diesel Power Station - a generating station in which diesel engine is used as the prime mover for electrical energy generating. Diesel power plants are widely used as standby supply of oil and gas industries, especially for supplying consumers of first and second categories. During power cut, diesel power generators are run to fulfill required demand.

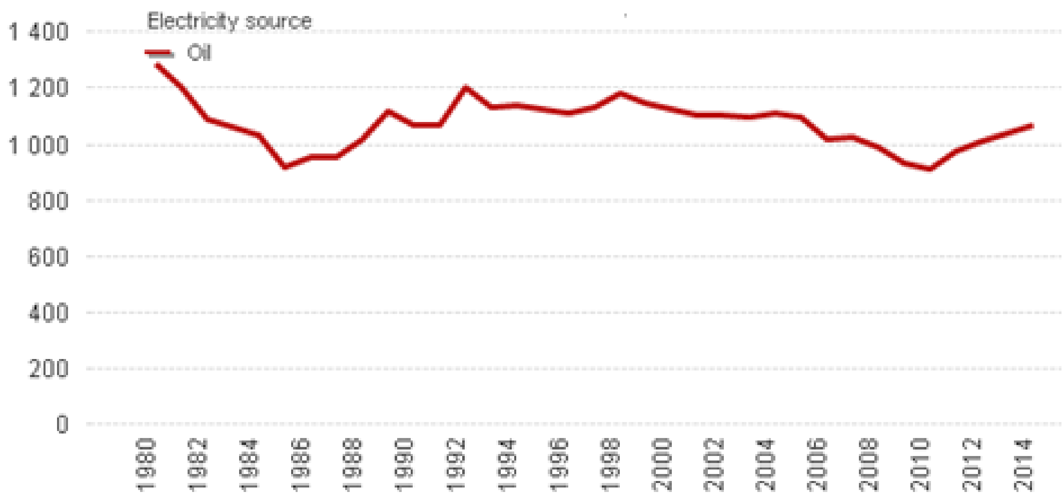

Figure 1.2. World electricity generation from oil [4]

Advantages:

- The design and layout of the plant are quite simple;
- It occupies less space, and it can be located at any place;
- It can be started quickly and can pick up load in a short time;
- There are no standby losses, and it requires less quantity of water for cooling and less operating staff;
- The overall cost is much less than cost of steam power station of the same capacity;
- The thermal efficiency of the plant is higher than that of a steam power station (35%);
- Cooling is easy and required smaller quantity of water in this type power station.

Disadvantages:

- The plan has high running charges as the fuel (i.e. diesel) used is costly;
- The plant does not work satisfactory under overload conditions for a long period;
- The plant can only generate relatively small power;
- The cost of lubrication and maintenance charges are generally high.

In addition to diesel generator set, there are many other auxiliaries attached to a diesel power station. In *fuel supply system* there are one storage tank strainers, fuel transfer pump and all day fuel tank. Oil is stored in storage tank. The oil pumped from main tank to dry tank with clearing in the strainer. In case of overflowing, there is additional overflow pipe to return oil from dry tank to main one. The oil is injected in the engine by fuel injection system.

Fuel combustion needs an oxygen; therefore, the *Air Intake System* is responsible for providing required amount of air into the combustor chamber. It consists of a pipe for supplying of fresh air to the engine. Filters are provided to remove dust particles from air because these particles can act as an abrasive in the engine cylinder. The exhaust gas is removed from engine, to the atmosphere by means of an *exhaust system*. A silencer is normally used in this system to reduce noise level of the engine.

Cooling System. The cooling system protects from overheating, which may lead to damage of the whole installation. The set temperature in required the range should be maintained, according to technical characteristics and conditions. The pump circulates water through cylinder and head jacket, the cooling water carries heat away from the engine. Then, the hot water is cooled down by cooling towers.

Lubricating System. The lubricating oil is collected in lube oil tank, from where it delivers by oil pump to the engine through oil filter and oil cooler to keep the temperature low.

Engine Starting System. For starting the diesel engine, the compressed air is used to force the initial rotation of the shaft. Especially for powerful sets, the compressed air stations are used, therefore the starting time increases.

Additionally, diesel power generators provide backup power to company's main facilities and operations. If there is an emergency or disaster and the main power is shut down, generators can assist with backup, allowing business to continue as usual. This can save the industry a huge amount of lost time and money. [6]

1.3 Gas-fired power plants

Gas-fired power plants - power plants that designed for stand-alone or back-up power generation by means of various types of gas combustion. They are of two main types: gas piston and gas turbine plants. They have structural and functional differences that determine the extent of their use and feasibility of the installation on a particular object. After analyzing the object specifics, pros and cons of each type, you can understand what type need to be chosen.

It is reasonable to apply the associated petroleum gas (APG) as fuel for autonomous power production installations. APG is stored in the dissolved state in in-place conditions, being escaped from oil in process of it extraction on a surface. In spite of the fact that gas is important raw material in petrochemistry and valuable fuel in power generation sector, the Russian Federation places first place in the world in terms of burning volumes. According to official statistics, 26.7 billion m^3 of APG have burned out by flares in Russia in 2011, however the World Wide Fund for Nature space monitoring shows that not less than 38 billion m^3 have burned out. [3, 13, 14]

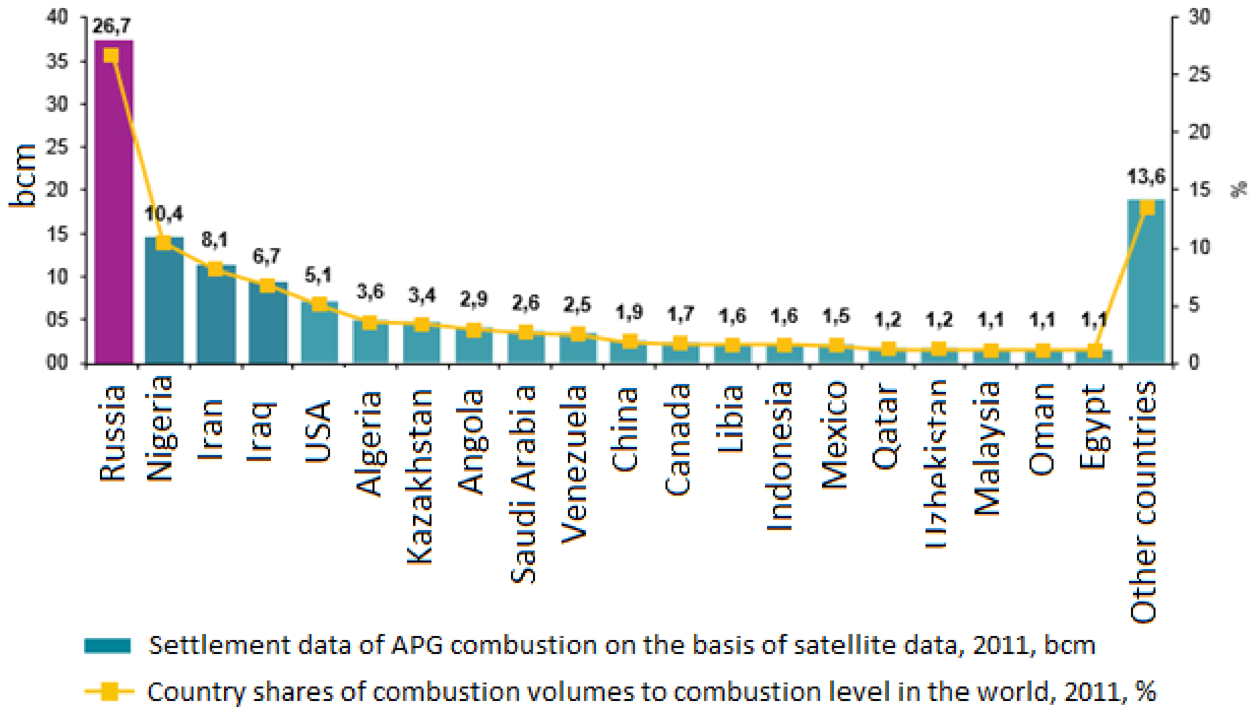

Figure 1.3. Gas burned out statistics [14]

APG combustion leads not only to huge financial losses due to uncollected hydrocarbonic raw materials, but also to considerable emissions of solid pollutants and deterioration in an ecological situation in oil-field areas. By estimates of the Ministry of Industry and Energy, 321,8 thousand tons of solid pollutants were released into the atmosphere in oil-extracting regions in 2004 (about 12% of total amount of emissions in Russia). Seven million tons of ethane, four million tons of propane, 2,6 million tons of butane were burned out on flare units. Oil and gas production entities lose about 13 billion dollars annually because of insufficient APG recycling rate. [14, 15]

In the Khanty-Mansiysk Autonomous Region, according to administration statistics, 7,6 billion m^3 of associated gas burns out annually by flare installations; that is comparable with devastation of 6,5 million tons of oil. According to results of the research financed by the World Bank, about a third part of the Russian APG burned by flare units ensure to be used, in case of the price level of 2007, will allow to gain additional annual income in the amount of 2,3 billion dollars, and will allow to reduce emissions of CO2 more than by 30 million tons/year [14, 15].

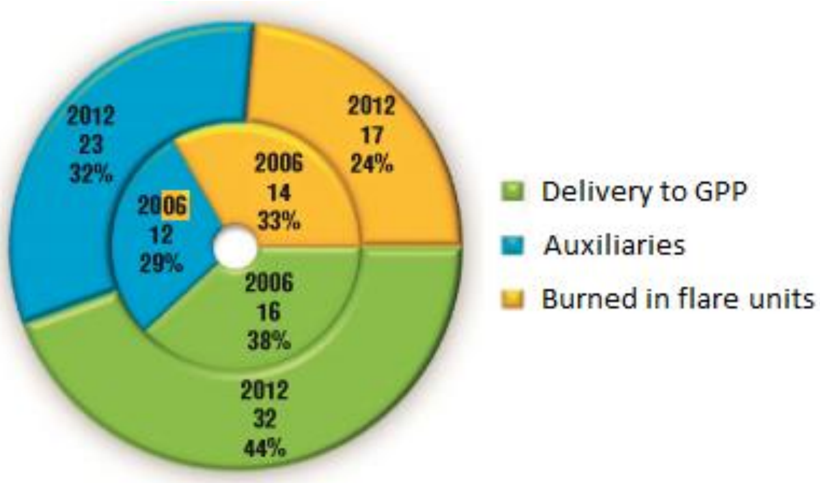

Figure 1.4. APG utilization dynamics in Russia, according to The Ministry of Industry and Energy, bcm [13]

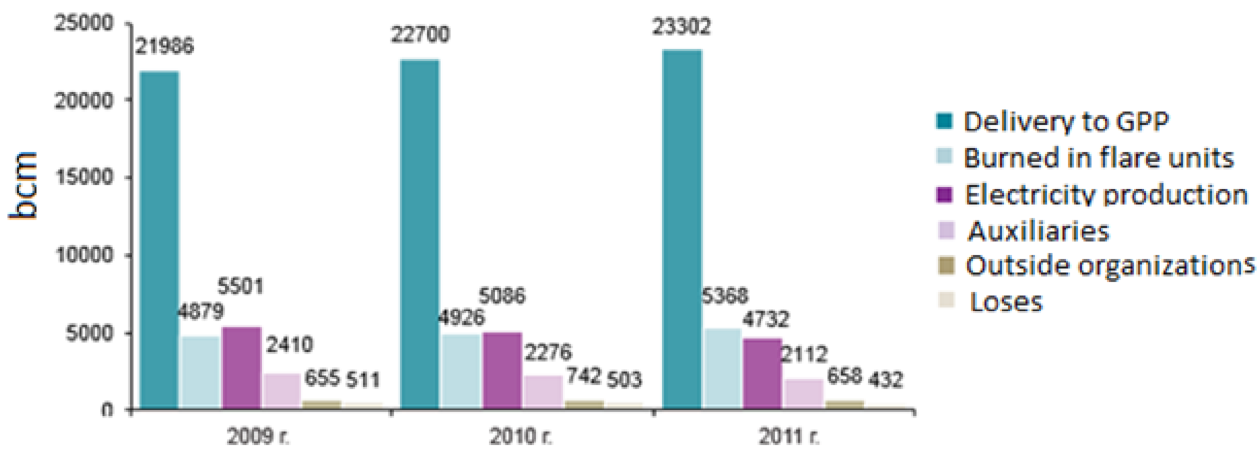

Figure 1.5. APG usage by purposes [13]

Insufficient extent of APG utilization was caused by lack of the tough regulating mechanisms, and insignificant penalties for environmental pollution. The required level of APG utilization gains 95% according to the government regulations of the Government of the Russian Federation No. 7 of January 8, 2009 "About measures for stimulation of reducing pollution of atmospheric air products of combustion of APG on flare units". Since 2014, increase in penalties for above-standard combustion of APG forces oil and gas companies to manage APG utilization more carefully. Some domestic oil companies have already reached required indicator on certain fields, but on the majority of oil fields, in particular beyond the Polar circle, the matter is resolved not completely. The most part of associated petroleum gas is burned by flare units, and for implementation of power supply, autonomous power plants are generally used. [1, 15]

At the same time, there are several methods of APG utilization:

- Deep-well injection for maintenance of reservoir pressure, thereby, increasing efficiency of oil extraction. However, in Russia, unlike some foreign countries, this method is used seldom since it is costly process;
- Utilization directly on the field for the local power generation going for ensuring needs of an oil field;
- Transportation on gas processing plants (GPP) for receipt of dry stripped gas, wide fraction of light hydrocarbons, the liquefied gases and stable natural gasoline [15]

Relatedly, power generation, when employing associated petroleum gas, is one of the most perspective approaches to the solution of an energy problem of remote production objects. The issue of turning from the centralized power supply systems to autonomous energy complexes is urgent in recent years. Besides, it is necessary to consider chromatographic composition of gas of individual wells for ensuring uninterrupted operation of power aggregates and determination of fuel exchangeability possibility. Before gas using as a fuel, it is necessary to carry out its preparation on separation plants to separate mechanical impurity, condensate, and oil. Further, the separated gas goes to heaters and compressors, then - to a power installation input. [3, 15]

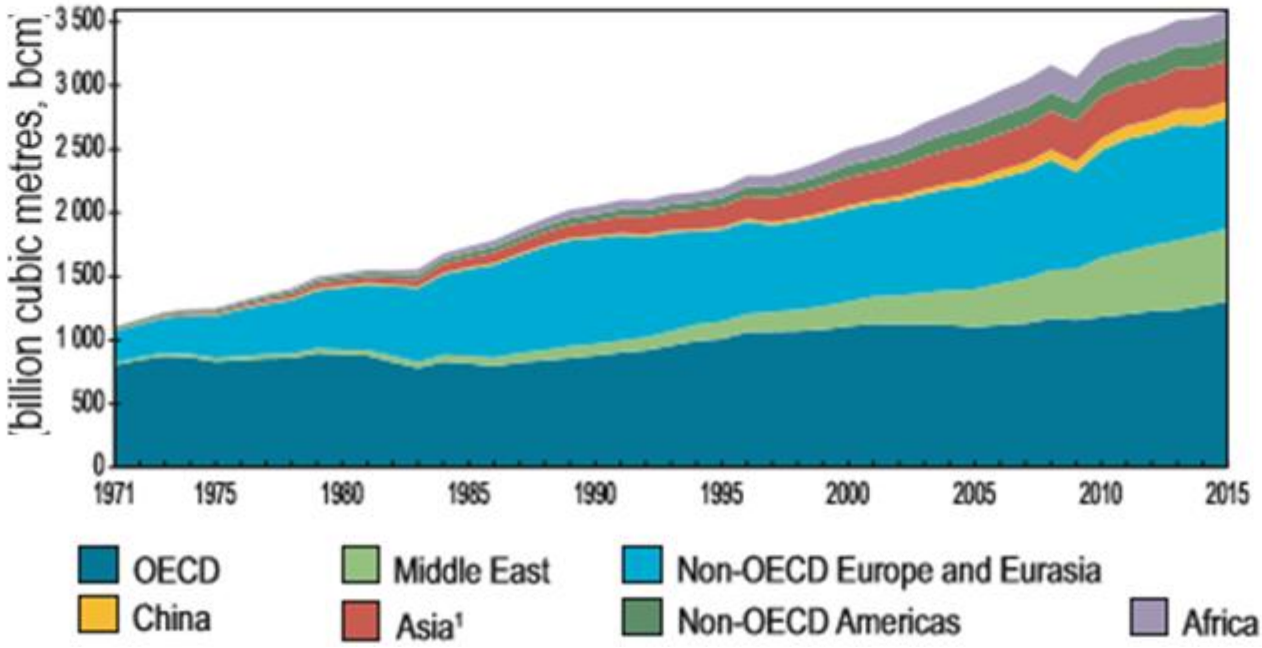

Figure 1.6. Natural gas production from 1971 to 2015 by region [12]

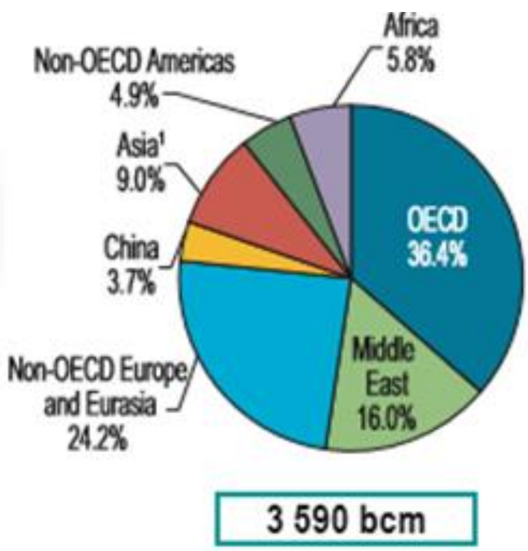

Figure 1.7. Natural gas production in 2015 by region [12]

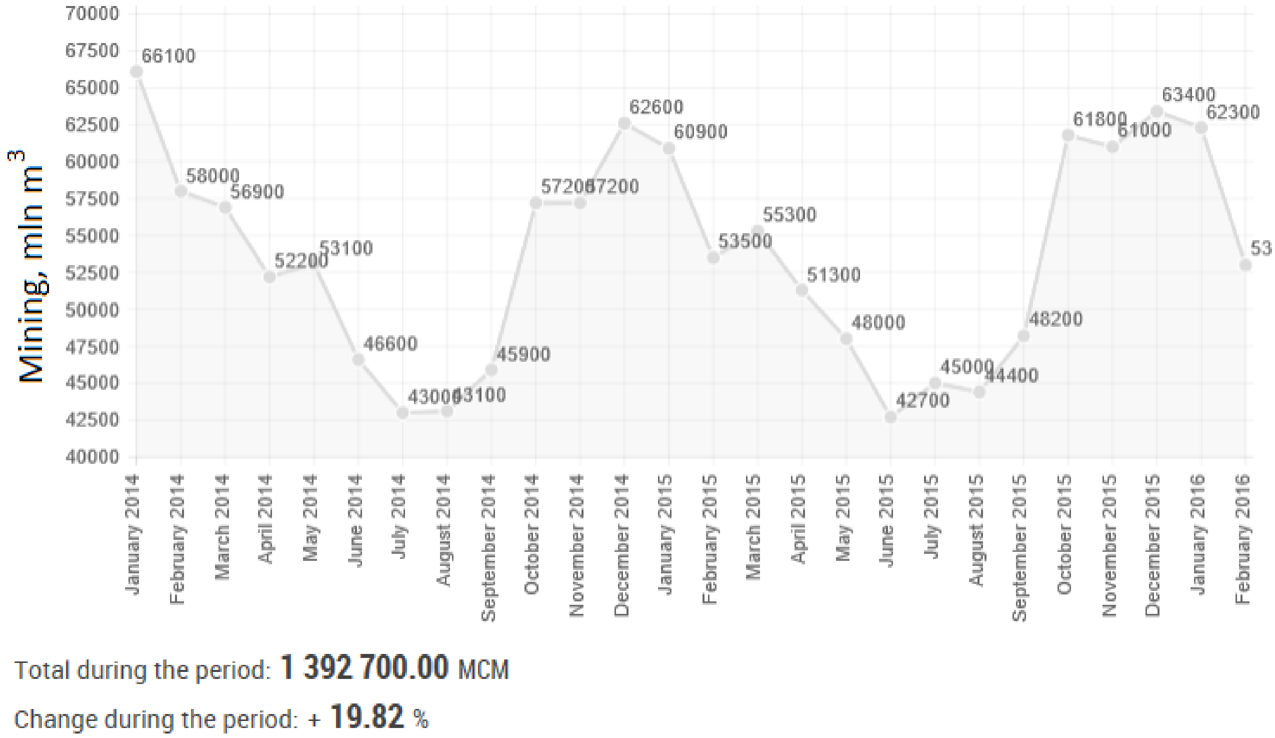

Figure 1.8. Natural gas mining in Russia [11]

In 2015, gas production amounts 635,5 billion cubic meters (taking into account the Crimea) that it is lower than the 2014 level on 6,5 billion cubic meters (-1,0%).

In structure of production there was a reduction of natural gas volumes by 12,5 billion cubic meters (-2,2%) and increase in extraction of APG. The APG share in gas production has grown from 11,3% in 2014 to 12,4% in 2015. [11]

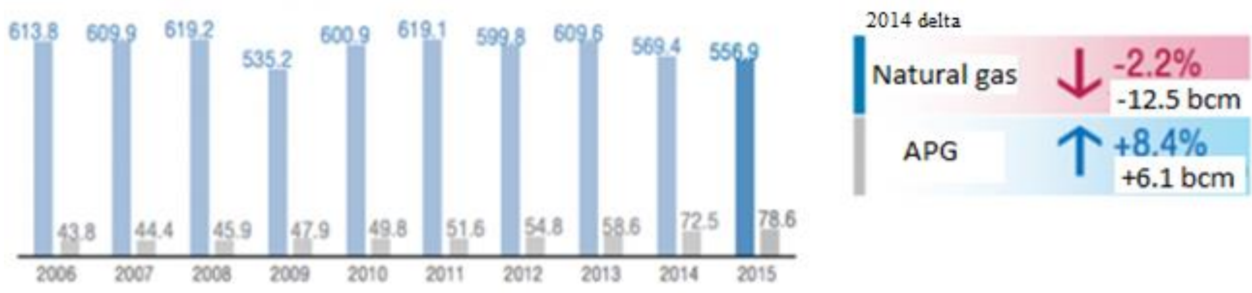

Figure 1.9. Natural gas and APG mining [11]

In 2015, the coefficient of APG efficient utilization has increased in comparison with 2014 from 85,5% to 88,2%. Increase in efficient use of APG up to 95% remains the main issue. [11]

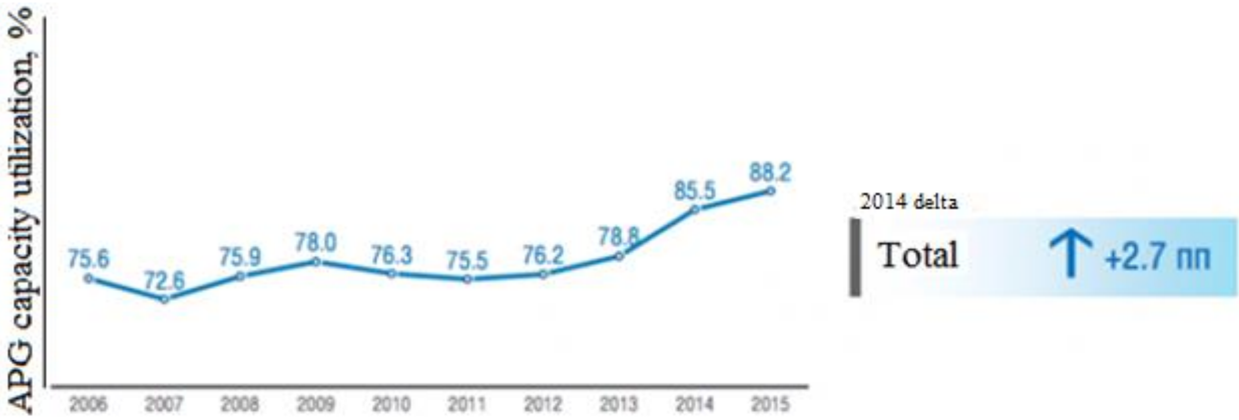

Figure 1.10. APG capacity utilization data, % [11]

Summing up, associated gas current market situation made unprofitable the process of gas transportation and processing. One of the most effective ways to use the associated gas and minimize emissions into the atmosphere is producing electricity and heat for oil and gas fields own needs. Today, such projects implement majority of large companies of the oil and gas industry, including Lukoil, TNK-BP, Tatneft, Novatek, Itera, Gazprom and others.

Gas-fired power plants application opens up various opportunities for efficient utilization of associated petroleum gas and reduction cost of electric power in 2-3 times in comparison with network tariffs, which leads to a significant reduction in energy intensity of oil production as a whole. [5, 6]

1.3.1 Gas piston power stations

Gas piston power plant is a generator, which is driven by an internal combustion engine running on gas.

Advantages:

- Moderate price
- Coefficient of efficiency is about 40% and it doesn't change depending on load
- Moderate mean specific fuel consumption
- Starting time (≈ 5 min.)
- Unlimited number of starts

Disadvantages:

- Overhaul cost achieves 70-90 % of total investment
- Limited no-load operation time
- High maintenance cost
- Lubrication severity
- Difficult cold start
- Harmful emissions for environment

If necessary, operation of several gas piston power plants can be synchronized to get required capacity and distribute the workload evenly. Parallel operation of gas piston power plants with the mains could be performed as parallel to the load or individually with different capacities where necessary to provide different rated capacity. This enables to achieve required output power and vary the load.

GPPP component parts:

- Heat–insulated block–box consisting of equipment modules;
- Gas generator unit;
- Automation system;
- Fuel gas supply system;
- Oil system;
- Cooling system with coolers and circulation pumps;
- Starting system;
- Exhaust system;

- Ventilation system;
- Heating system for transportation and operation;
- Operating and emergency lighting system;
- Automatic fire alarm and fire warning system;
- Automatic gas fire–fighting unit;
- Gas analysis system by fuel gas;
- An optional dispatching desk, remote control.

Gas piston power plants requires high fuel quality; therefore, their usage may lead to range of difficulties. High risk of detonation does not allow using them at the fields with low fuel quality or hydrogen sulfide content of more than 0.1 percent without the construction of the preliminary gas preparation system, which significantly increases the capital cost of gas-piston power plants. Gas piston power station is often operated with a load no more than 40-60% of the nominal power because of high risk of fuel detonation. This leads to higher costs of equipment maintenance and to the rapid breakdown. [1, 5, 6]

1.3.2 Gas turbine power stations

A generating station, which employs gas turbine as the prime mover for the generation of electrical energy is known as a gas turbine power plant. In gas turbine, air is used as the working medium. The air is compressed by compressor and is led to the combustion chamber where heat is added to air, thus raising its temperature. The hot and high-pressure air from the combustion chamber passes to the gas turbine, expands and does the mechanical energy.

The gas turbines are being installed in many power plants for oil and gas industry as complex machines .Usually, they include three main components:

- *The compressor* is increasing the pressure, supply the engine with air and inject it to the combustion chamber at high speed.
- *The combustion system* injects steady fuel steam through nozzles to combustion chamber. It is mixing with air and is burning at high temperatures (more than 1000 degrees Celsius). High-pressure gas stream enters and expands through the turbine section.
- *The turbine* is a complex assembly, which consist of aerofoil-section blades for creating a rotary moment from expanding via turbine of injected hot combustion gas.

The most crucial parameter, which influences a turbine efficiency, is the turbine operation temperature. Generally, the higher temperature, the higher efficiency, and the operation could be more feasible from economic point of view. The flow through turbine can achieve the temperature of 1300 degrees Celsius, while some metals in the turbine can withstand temperatures only from 800 to 950 degrees Celsius. Thus, the air from the compressor could be used as cooling medium for turbine, reducing total efficiency of thermal cycle.

The way of efficiency increasing is to implement a waste heat exchanger or heat recovery steam generator (HRSG) to utilize the turbine exhaust energy. A waste heat exchanger retains waste heat from the turbine exhaust system to preheat the compressor discharge air before it enters the combustion chamber. [5]

Advantages:

- Lower overhaul cost (10-20 % of total investment);
- The initial and operation costs are much lower than that of equivalent steam power station;
- It requires comparatively less water;
- The maintenance charge is less, comparing with gas piston stations;
- It can be started quickly from cold conditions;
- There are no standby losses;
- Less level of noise and vibration.

Disadvantages:

- Coefficient of efficiency directly-proportional depends on load;
- High mean specific fuel consumption;
- Starting time (≈ 15 min.).

The application of gas turbine power plants gives the opportunity to organize a reliable and economic power supply of oil and gas fields. The block modular design of installations increases the reliability of the plant and gives the possibility to switch on/out individual units from operation without operation interrupting the entire power plant. [5, 6]

However, the most important issue - the economic efficiency of own power plant construction. The following indicators have been taken mostly as a basis for calculation:

- Required electric load;
- Network company joining costs;
- Grid connection costs;
- Electricity tariff;
- Power plant building costs;
- Main equipment costs;
- Maintenance and repair costs;
- Power loses costs;
- Life cycle period.

2. Centralized and autonomous power supply variants and technical calculations

2.1 Krapivinskoe oil-field electrical load data description

The Krapivinskoe oil-field general layout illustrates location of well pads, their squares and a possible connection point to the feeder line.

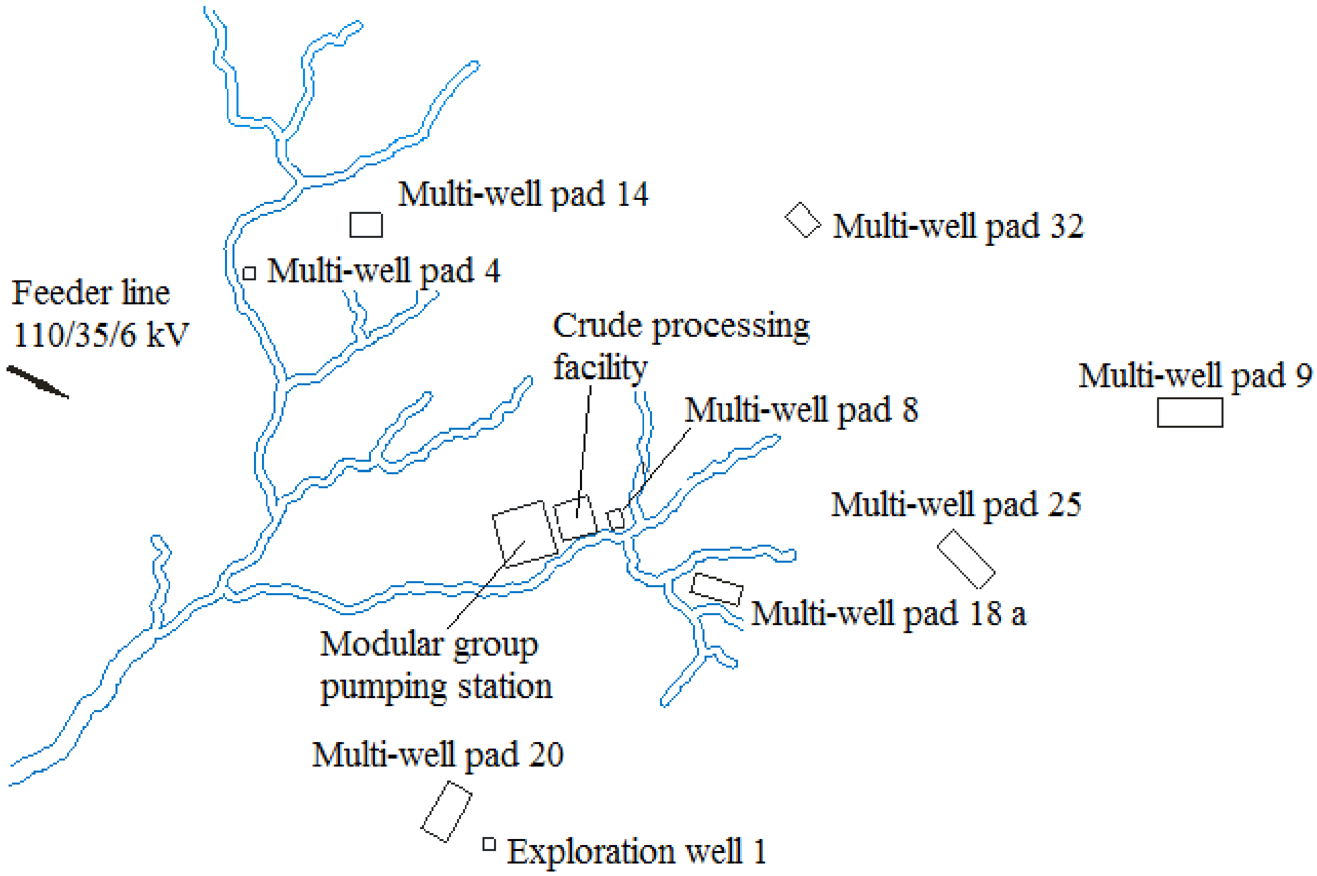

Figure 2.1. Krapivinskoe oil-field general layout

I've performed and systematized calculations of Krapivinskoe oil-field valuable electric parameters in the form of the table 2.1 given below. The carried-out calculations, by a demand coefficient method, have determined the active, reactive, total power load of Krapivinskoe oil field, and also active energy consumption is found. These calculations are used for a right choice of sections of feeder lines, switching and protective devices, also for further economical evaluation of centrilized and authonomous power supply system variants.

Table 2.1. Krapivinskoe oil-field characteristics

Factor	Value	Unit of measure
Active power load	16,188	MW
Reactive power load	10,076	MVAr
Total power load	19,068	MVA
Electric load utilization time Tm	7500	hours
Active energy consumption (annual)	121 410	MWh
Maximum duration time of loses, τ_{max}	6692	hours

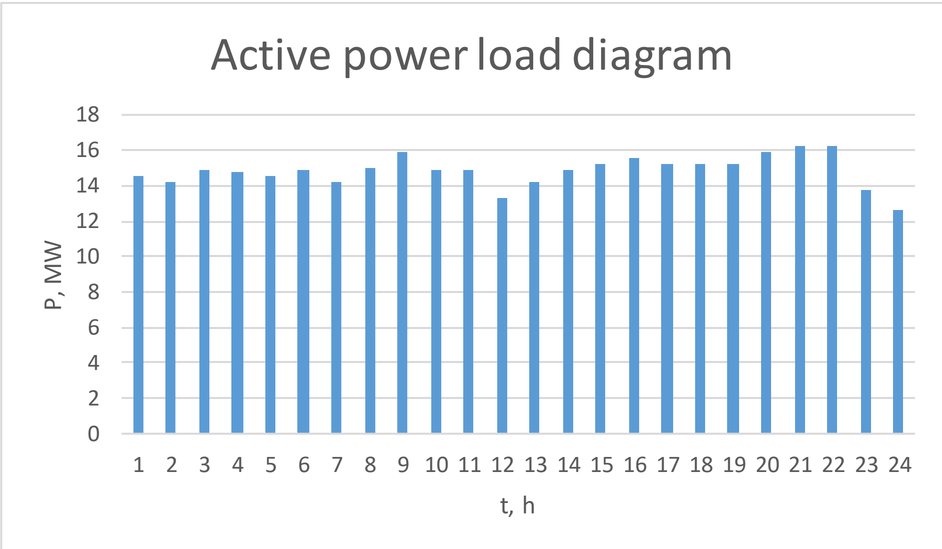

Figure 2.2. Krapivinskoe oil-field daily active load diagram

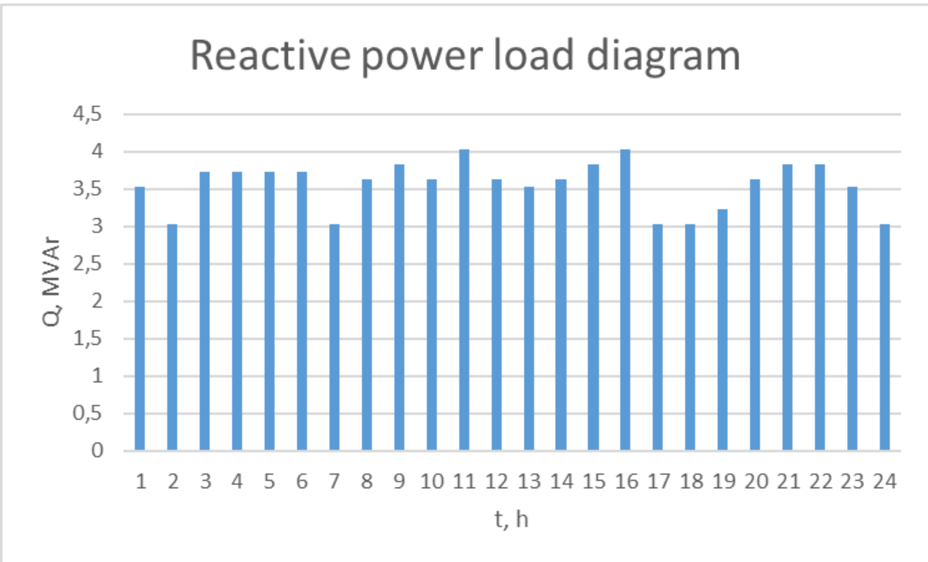

Figure 2.3. Krapivinskoe oil-field daily reactive load diagram

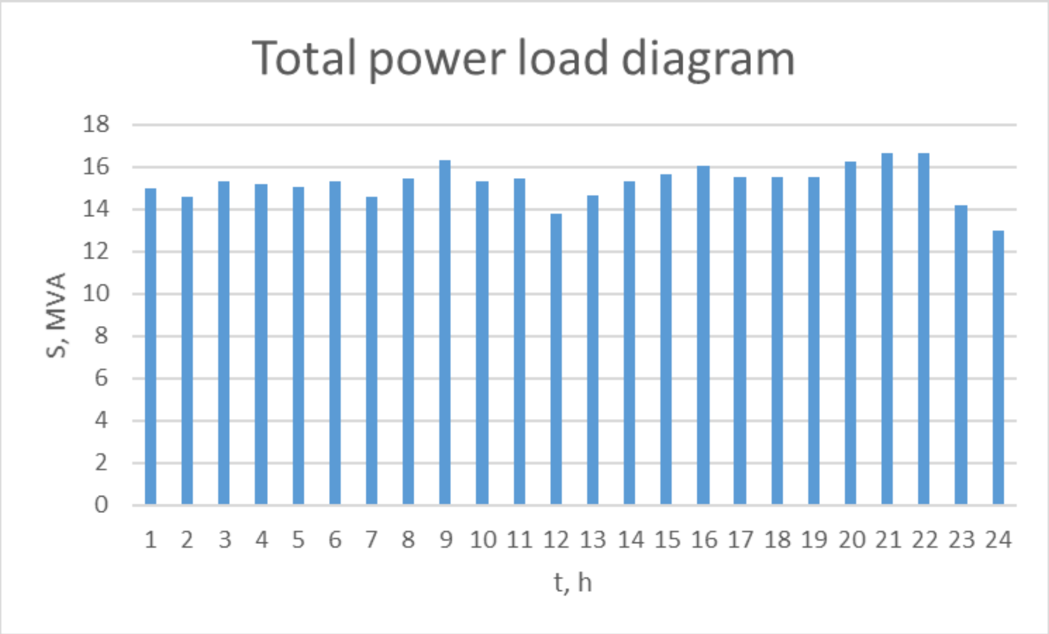

Figure 2.4. Krapivinskoe oil-field daily total load diagram

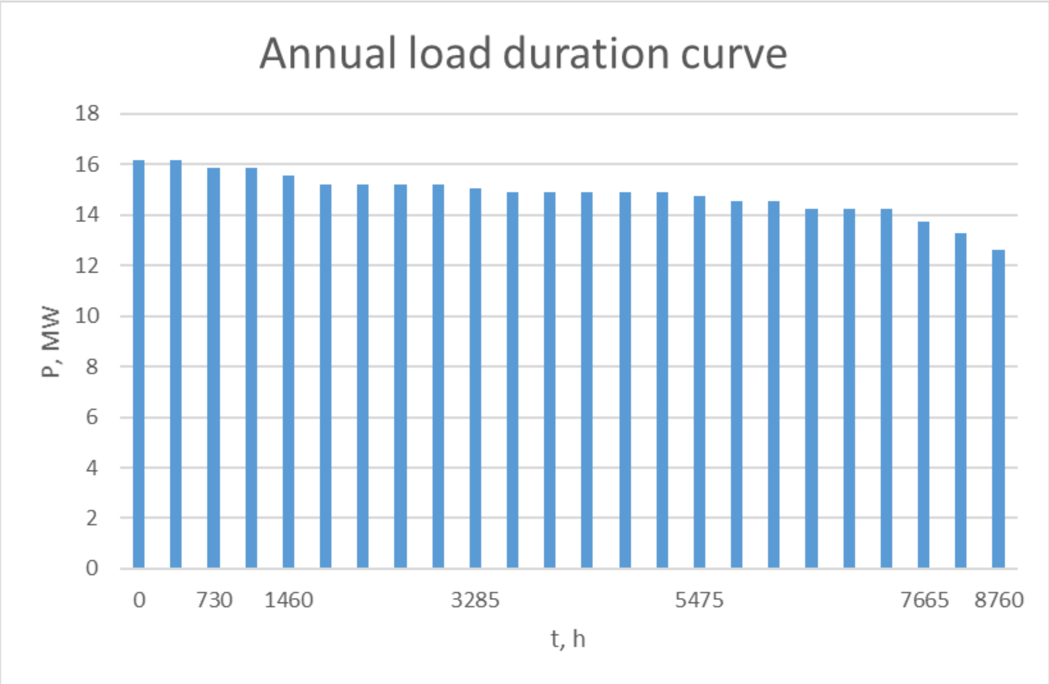

Figure 2.5. Krapivinskoe oil-field annual load duration diagram

As is evident from the foregoing, Krapivinskoe oil-field daily load diagrams have typical form for oil and gas industries and enterprices with triple-shift working shcedule and constant production.

2.2 Krapivinskoe oil-field power supply system variants calculations

2.2.1 Centralized power supply system

The centralized power supply has been performed by 110 kV overhead line from power network, according to recommendations provided in [8] (rated power of oil field exceeds 16 MW and calculated voltage level equals 70 kV). The technical decision justification of chosen voltage level:

$$U = \frac{1000}{\sqrt{\frac{500}{L} + \frac{2500}{P}}} = \frac{1000}{\sqrt{\frac{500}{10} + \frac{2500}{16{,}188}}} \approx 70\ kV \qquad (1)$$

where L – feeder overhead line length, km; P –oilfield active power load, MW. [9]

The main step-down substation (MSS) is located on the enterprise area according to calculated electric load center. There are two three-phase double-winding transformers on MSS: TDN – 16000/110. On the 6 kV side assign transfer busbar operated by vacuum circuit breaker with automatic transfer switch.

MSS transformers required power:

$$S_{nom.tr.} = \frac{S_{R.MSS}}{n_{tr} \cdot \beta_l} \qquad (2)$$

where $S_{R.MSS}$– total rated enterprise power from HV MSS point; β_l = 0,7 - MSS load coefficient;

n_{tr} – MSS transformers quantity. [8]

Obtain:

$$S_{nom.tr} = \frac{19068}{2 \cdot 0{,}7} = 13620\ \text{kVA}$$

The received value rounded up to the bigger standard value from standard set. Confirm two transformers labeled as: TDN-16000/110. [9]

In post-emergency mode, one transformer will be able to supply the enterprise:

$$S_{R.MSS} < 1{,}4 \cdot S_{nom.tr}, [9] \qquad (3)$$

$$19068\ [\text{kVA}] < 22400\ \text{kVA}$$

Feeder lines - lines labeled as AS (aluminum/steel lines). Cross section calculations have been performed by economic current density, MSS rated current:

$$I_R = \frac{S_{R.MSS}}{2 \cdot \sqrt{3} \cdot U_{nom}};[9]. \tag{4}$$

$$I_R = \frac{19068}{2 \cdot \sqrt{3} \cdot 110} = 50,04 \text{ A}$$

In post-emergency and repair mode:

$$I_{p.e.} = \frac{S_{R.MSS}}{\sqrt{3} \cdot U_{nom}}; \tag{5}$$

$$I_{p.e.} = \frac{19068}{\sqrt{3} \cdot 110} = 100,08 \text{ A}$$

At number of working shifts equal 3 and durations of the shift equal to 8 hours accept annual maximum electric load utilization time as T_m =7500 hours. [8] At T_m=7500 hours the economic current density for Al wires: j_{ec}=1 A/mm^2. [9]

Economically feasible wire cross section:

$$F_{ec} = \frac{I_R}{j_{ec}} \tag{6}$$

$$F_{ec} = \frac{50,04}{1} = 50,04 \text{ mm}^2$$

where j_{ec} - economic current density;

I_R - MSS rated current.

The received value rounded up to the bigger standard value from standard cross section set and confirm wire label: AS–70/11. The permissible current for such cross section is: I_{perm}=265 A. [9]

Confirmed cross section should be checked up by heat current carrying capacity:

$$1,3 \cdot I_{perm} \geq I_{p.e.}, \tag{7}$$

where I_{perm} – permissible current, A

344,5 A ≥ 100.08 A – meet the requirement.

Besides, confirmed cross section should be checked up by:

a) corona effect requirements

According to Rules of Electrical Facilities Maintenance ([8]), the wire should be checked up by maximum corona loses. However, the minimum cross section (corona effect requirements) is equal to 70 mm².

$$1{,}07\ E \leq 0{,}9\ E_0 \tag{8}$$

where E – wire electrostatic field strength, kV/sm, which defined by formula:

$$E = \frac{0.354 \cdot U}{r_0 \cdot \lg \frac{D_m}{r_0}} \tag{9}$$

where U – voltage level, kV;

r_0 – single wire radius, sm;

D_m - geometric mean distance between wires, sm.

E_o – critical electrostatic field strength, kV/sm, which defined by formula:

$$E_0 = 30.3 \cdot m(1 + \frac{0.299}{\sqrt{r_0}}) \tag{10}$$

where m – wire roughness coefficient.

For AS-70/11 obtain:

$$E = \frac{0.354 \cdot 110}{0.57 \cdot \lg \frac{300}{0.57}} = 25.1 \text{ kV/sm}$$

$$E_0 = 30.3 \cdot 0.82 \cdot \left(1 + \frac{0.299}{\sqrt{0.57}}\right) = 34.7 \text{ kV/sm}$$

$$1{,}07 \cdot E = 1{,}07 \cdot 25{,}1 = 26{,}9 \text{ kV/sm;}$$

$$0{,}9 \cdot Eo = 0{,}9 \cdot 34{,}7 = 31{,}2 \text{ kV/sm.}$$

Consequently, the wire meets the corona requirement.

b) mechanical integrity requirement:

$$F_{rated} \geq F_{min.mech} = 25 \text{ mm}^2, [9] \qquad (11)$$

where F_{rated}- rated wire cross section, mm^2;

$F_{min.mech}$- minimum wire cross section from mechanical integrity requirement, mm^2.

70 mm^2 ≥ 25 mm^2 – meet the requirement;

c) admissible voltage loss requirement:

$$l_{perm} = l_{\Delta U\%} \cdot \Delta U_{perm\%} \cdot k_d \geq 1 \text{ [9]} \qquad (12)$$

where $l_{\Delta U 1\%}$ – line length at full load of 1% of loss of voltage, km;

$\Delta U_{perm\%}$ – permissible voltage loss, %;

$\Delta U_{perm\%} = 5$ %;

$k_d = \frac{I_{perm}}{I_{rated}}$ – return coefficient to coefficient of the line load;

l_{perm} – permissible line length, km;

l – real line length, km.

According [9] confirm $l_{\Delta U1\%} = 2{,}19$ km.

Obtain:

$$l_{perm} = 2.19 \cdot 5 \cdot \frac{265}{50.04} = 58 \text{ km}$$

Real line length l = 10 km.

58 km > l = 10 km, the wire meets admissible voltage loss requirements.

Consequently, enterprise centralized power supply is performed from power system substation by two 110 kV overhead lines AS–70/11 on steel double-chain pylons.

The MSS is located in electric load center spread zone. Two transformers (types: TDN–16000/110) are installed into MSS. At 6 kV side the single busbar system with two sections operated by vacuum circuit breaker is confirmed.

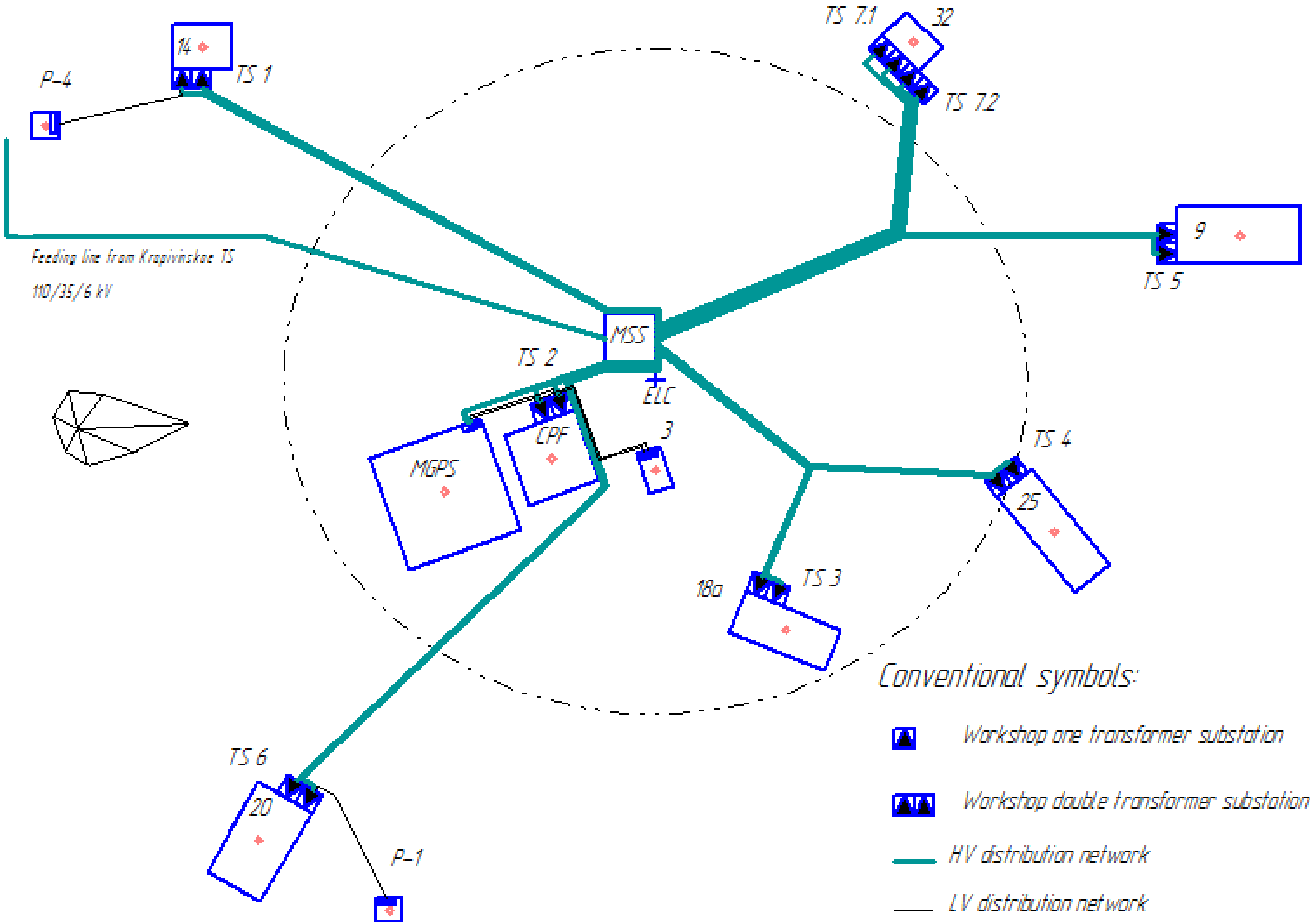

Figure 2.6. Centralized power supply system general layout

2.2.2 Autonomous power supply system

Internal combustion gas reciprocating engine is used as generator drives when generator unit output less than 3.5 MW; otherwise, gas-turbine installation is applied.

The choice of quantity, capacity and commissioning period is carried out based on following data:

- Maximum oilfield load and it's growth potential;
- Associated gas resources availability;
- Power redundancy level according to supply security rate.

In addition, the following conditions should be complied:

- Generating unit types number should be minimal;
- Power plant capacity factor should allow to have required spinning reserve;
- Availability factor no less than 0.99. [1]

Power plant complete set should assure minimal interruption intervals, maximal survivability of oil & gas production process in extremal conditions. Therefore, additional power should be installed to ensure on-time possibilities of equipment maintenance inspections, repairs and overhauls without plant nominal load decreasing.

Power interruption time for majority of consumers in oil and gas industry should be equal to automatic standby activation time. Thus, required spinning reserve need to be installed in such a manner, that properly functioning generation units are able to provide energy to whole system load. Spinning reserve allowed value is defined by load factor taking into consideration overload capability.

Table 2.2. Proper load factor determination data [1]

The number of generators, which operates in multiple	2	3	4	5	6	7	8	9	10
Optimal load factor	0.5	0.67	0.75	0.8	0.83	0.857	0.875	0.89	0.9

Taking into account provided data and assuming APG availability, the number of generators, which operates in multiple, could be defined from the formula [1]:

$$n_{GTG} \geq \frac{P_{мах}}{P_{nom} * К_{load}} \tag{13}$$

where $P_{мах}$ – maximum oil field load, MW;

P_{nom} - generation unit nominal output capacity, MW;

$К_{load}$ - generation unit required load factor.

Number of block-modular gas turbine installations based on gas turbines with output capacity 16 MW are chosen according to formula:

$$n_{GTG} \geq \frac{P_{мах}}{P_{nom} * К_{load}} = \frac{16.188}{16 * 0,5} = 2.02 \tag{14}$$

Confirm two gas turbine generators GTG – 16. In this case required load factor equals 0.5, in case of failure of one GTG – 16, another one will be able to supply all system, because maximum output capacity equals 20 MVA.

Block-modular gas turbine installations based on das turbines with output capacity 16 MW:

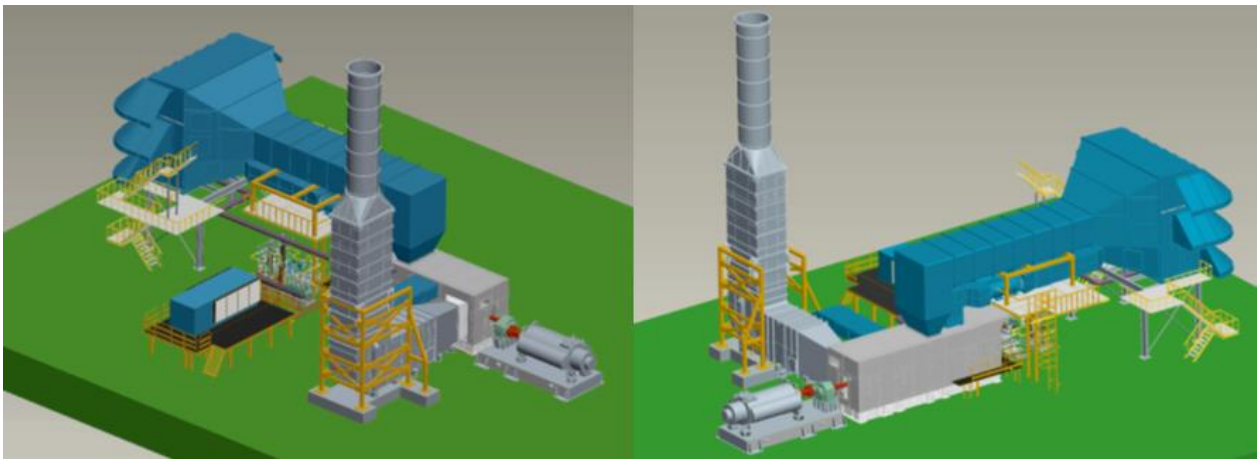

Figure 2.7. Gas turbine installation view [10]

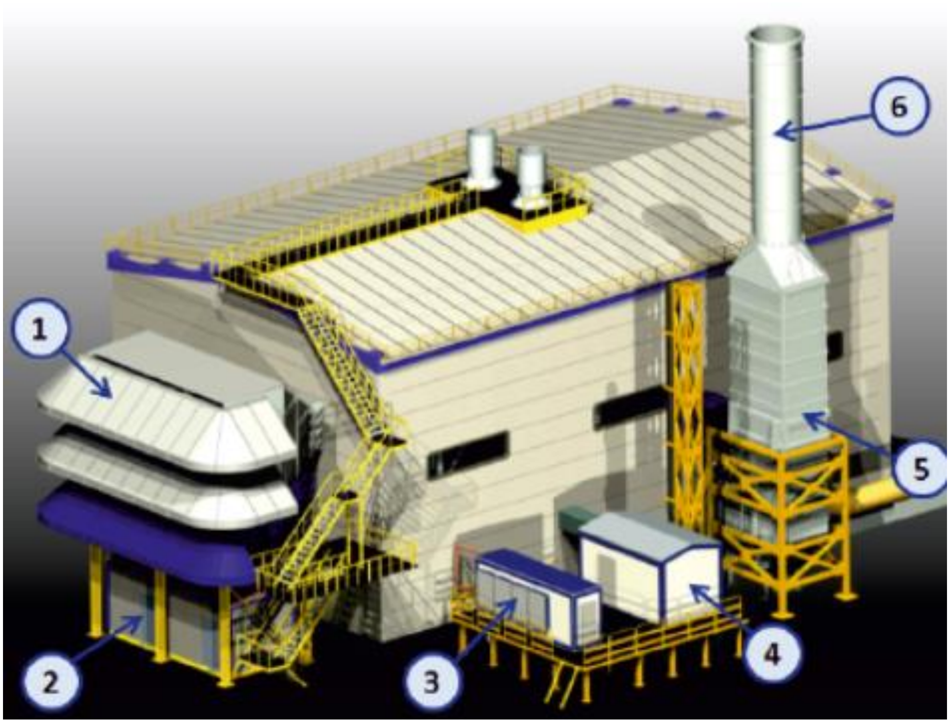

Figure 2.8. GTG – 16 block-modular assembly with subsystems: 1 - inlet air filter unit, 2 - antifire equipment, 3 – air oil cooler, 4 – air heater unit, 5 – gas duct with noise limiter, 6 - exhaust pipe. [10]

According to [10] GTG – 16 assemble include:

- Internal combustion gas reciprocating engine;
- Gas turbine;
- Turbine-driven generator;
- Gear set between turbine and generator;
- Inlet air filter unit;
- Exhaust-heat boiler;
- Fuel gas booster compressor;
- Air, gas duct system;
- Automated process control system;
- Electrical equipment;
- Metal frameworks, equipment inspection areas.

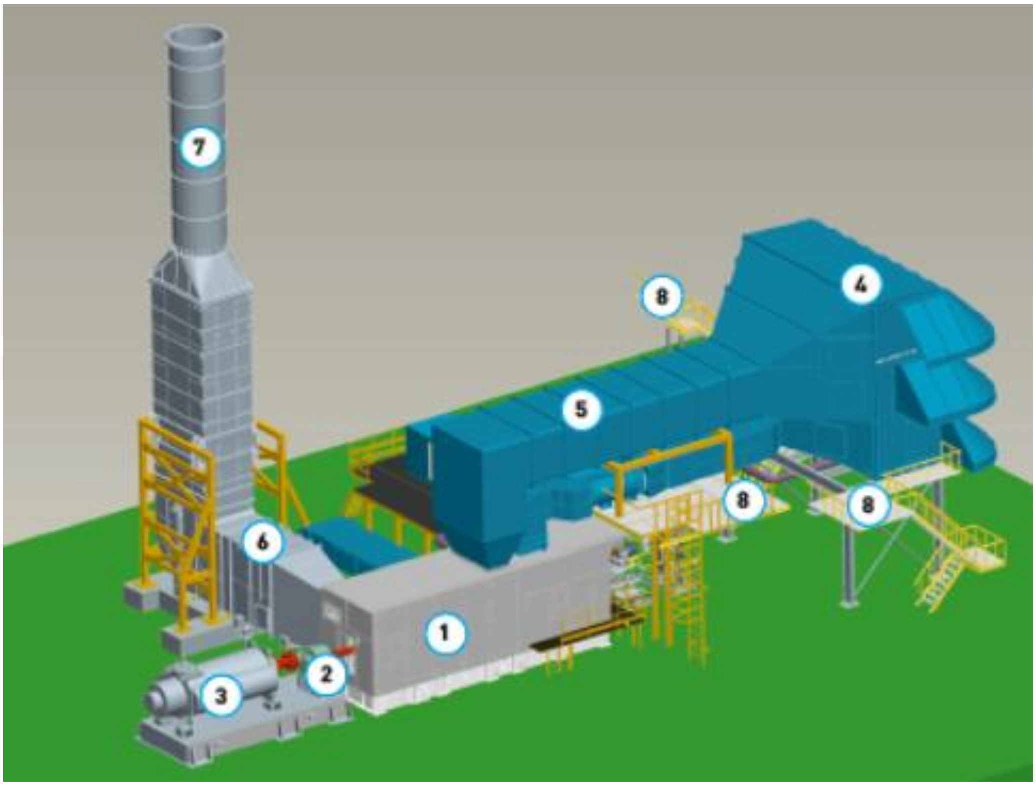

Figure 2.9. Power unit GTG – 16: 1- gas turbine, 2 – gear set, 3 – turbine-driven generator, 4 - inlet air filter unit, 5 – cycle air duct, 6 - gas duct with noise limiter, 7 – exhaust pipe, 8 - equipment inspection areas. [10]

Table 2.3. Technical specifications of gas engine according ISO standards [10]

Item	**Unit measure**	**Value**
Shaft power	MW	16.5
Turbine efficiency coefficient	%	37.0
Exhaust gas flow	Kg/s	54.3
Exhaust gas temperature	ºC	490
Compression index		19
Fuel consumption	Kg/s	0.892
Gas generator rotor shift speed, maximum	r/min	10200
Rotor output shaft speed, nominal	r/min	7800
Emission: NOx COx	Mg/m^3	 ≤50 ≤40
Overall dimensions	m	11.6 x 3.6 x 4.2
Gas turbine weight	t	75
Assigned lifetime to overhaul	h	≈ 200 000

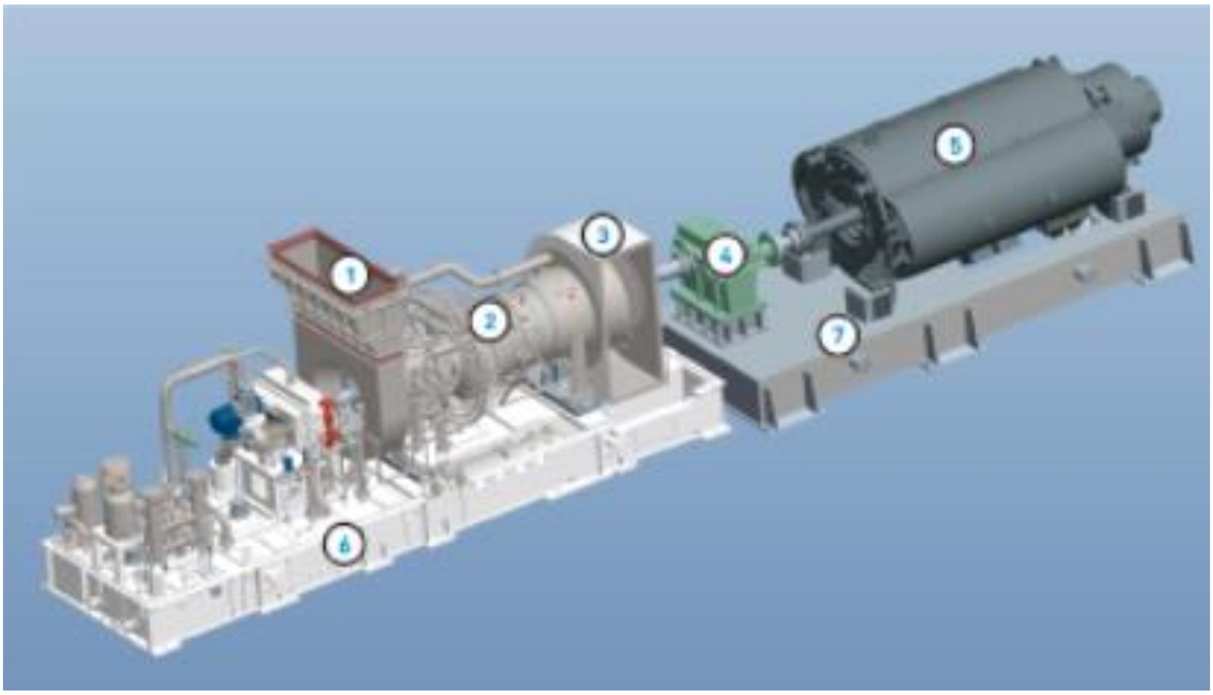

Figure 2.10. Core equipment of power unit: 1 - inlet fitting, 2 – engine, 3 - exhaust pipe, 4 – gear set, 5 – generator, 6 - engine frame, 7 – gear set and generator frame. [10]

Table 2.4. GTG – 16 maintenance characteristics [10]

Item	**Unit measure**	**Value**
Generator capacity	MW	16.0
Efficiency coefficient (electrical)	%	35.86
Exhaust gas flow	Kg/s	54.3
Exhaust gas temperature	°C	490
Fuel consumption	Kg/s	0.892
Outward air operation temperature	°C	from -60 to +50

Generator

Synchronous bipolar three-phase generator is installed as GTG – 16 generation unit. The nominal output capacity equals 16 MW, total capacity – 20 MVA, rotor rotation speed – 3000 r/min., efficiency coefficient in nominal operation mode – 98.1%, cooling system - double-loop cooling: air internal loop and liquid outward loop.

Single-reduction gear unit turns turbine shaft speed (7800 r/min) to generator shaft speed (3000 r/min.). [10]

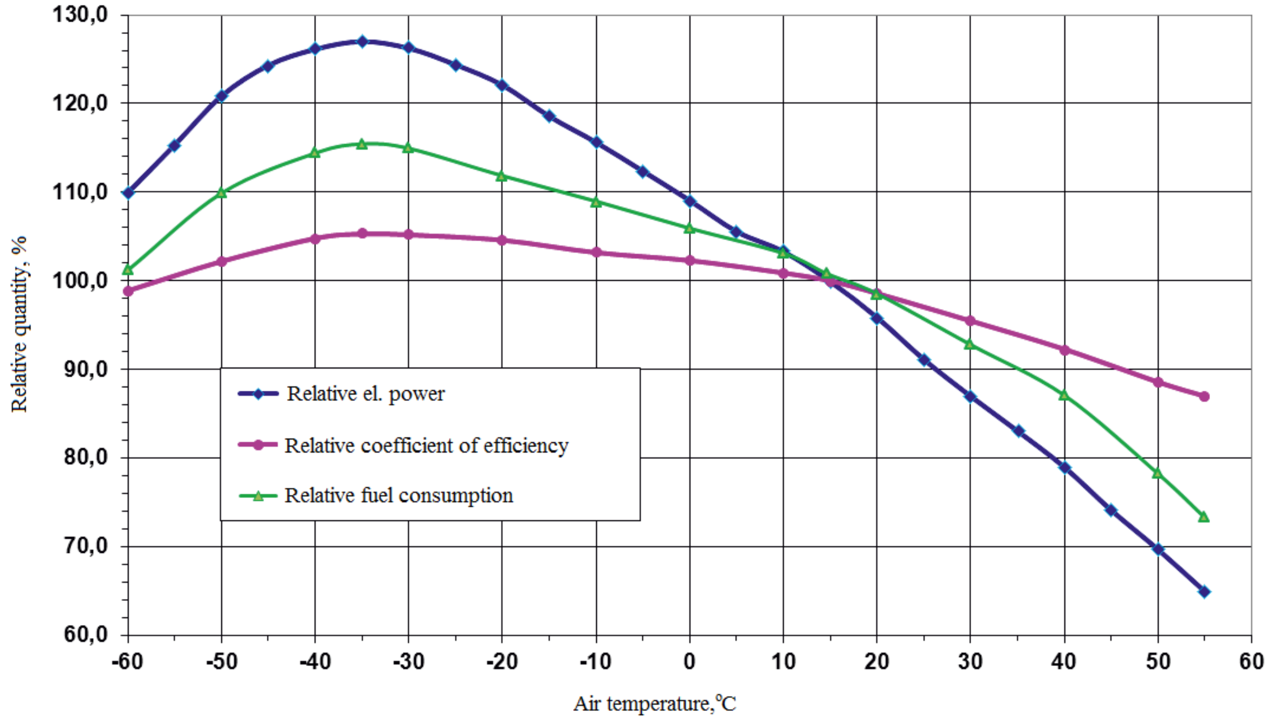

Figure 2.11. Dependence of relative values on air temperature [10]

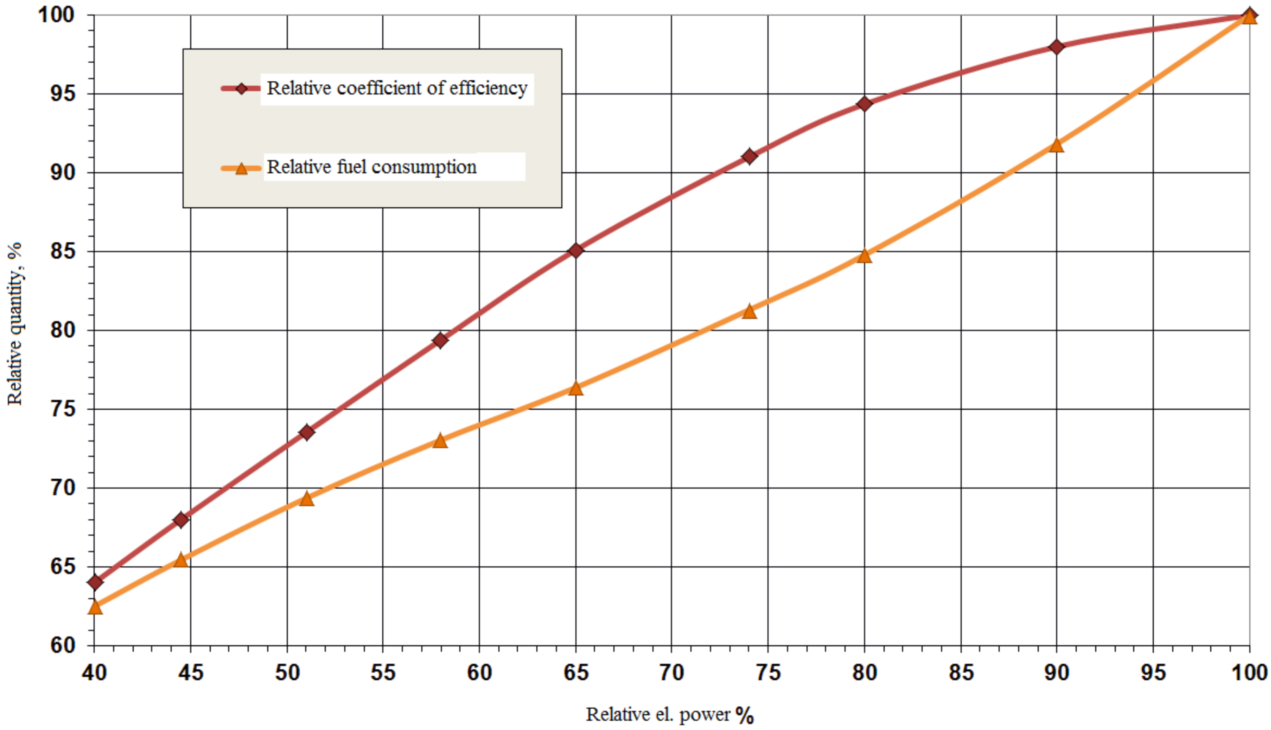

Figure 2.12. Dependence of relative efficiency coefficient and fuel consumption on relative electric power [10]

The following diagram illustrates GTG installation fuel consumption. Calculations have been performed by taking into account the dependence of fuel consumption on relative electrical power (figure 2.12) and Krapivinskoe oil-field daily load curve (figure 2.2), using the linear interpolation. Full daily calculation results, are presented in Appendix 1.

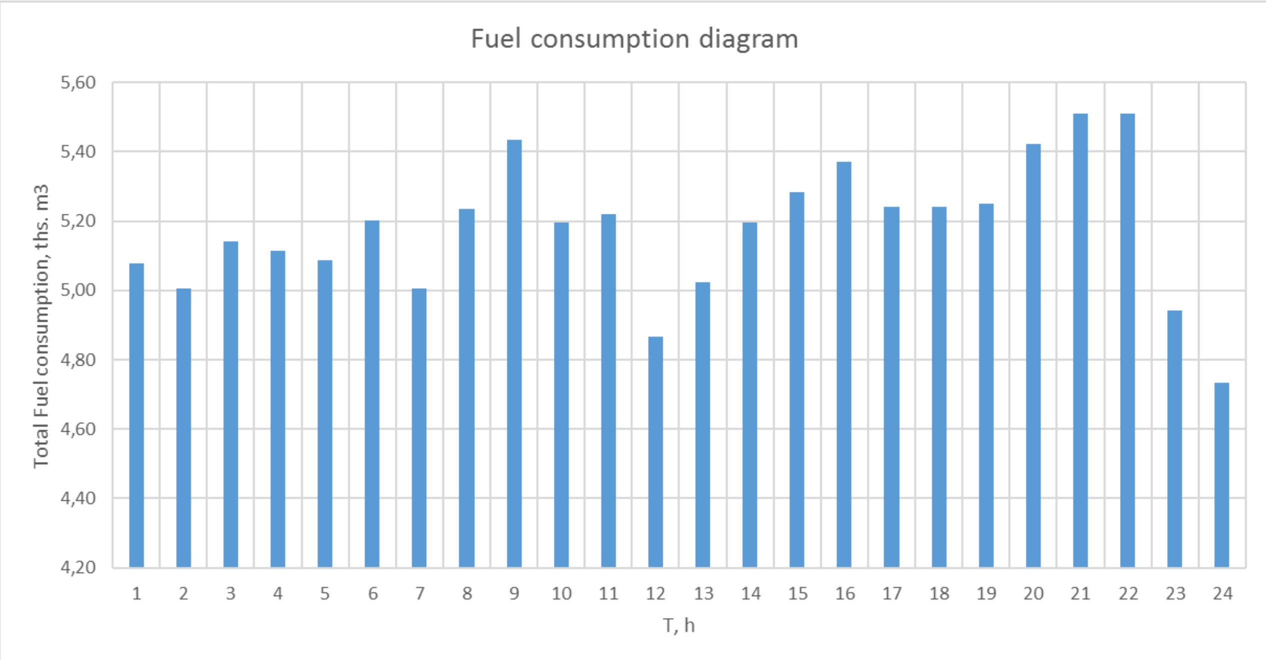

Figure 2.13. Daily fuel consumption diagram

Hours fuel consumption calculation (for the first hour):

$$G_{hour} = \frac{G_{sp} \cdot 3600 \cdot \beta_{GTG} \cdot k_{cons}}{\rho_{APG}} = \frac{2 \cdot 0.892 \cdot 3600 \cdot 0.786 \cdot 0.8335}{0.78} = 5080 \text{ m}^3$$

where G_{sp} – specific fuel consumption of one GTG – 16 installation, kg/s [10];

3600 – number of seconds in one hour;

β_{GTG} – load factor of GTG – 16 installation;

k_{cons} – fuel consumption factor, related with load factor [10];

ρ_{APG} – density of associated petroleum gas, kg/m^3. [6]

$$G_{year} = \sum_{i=1}^{24} G_{hour\ i} \cdot 24 \cdot 365 = 124\,316 \cdot 24 \cdot 365 = 45\,375\,800 \text{ m}^3$$

Deduced values of APG consumption will be used in further economic evaluation of the project to calculate reduction in fees and penalties for APG burning on flare facility for the variant of autonomous power supply system.

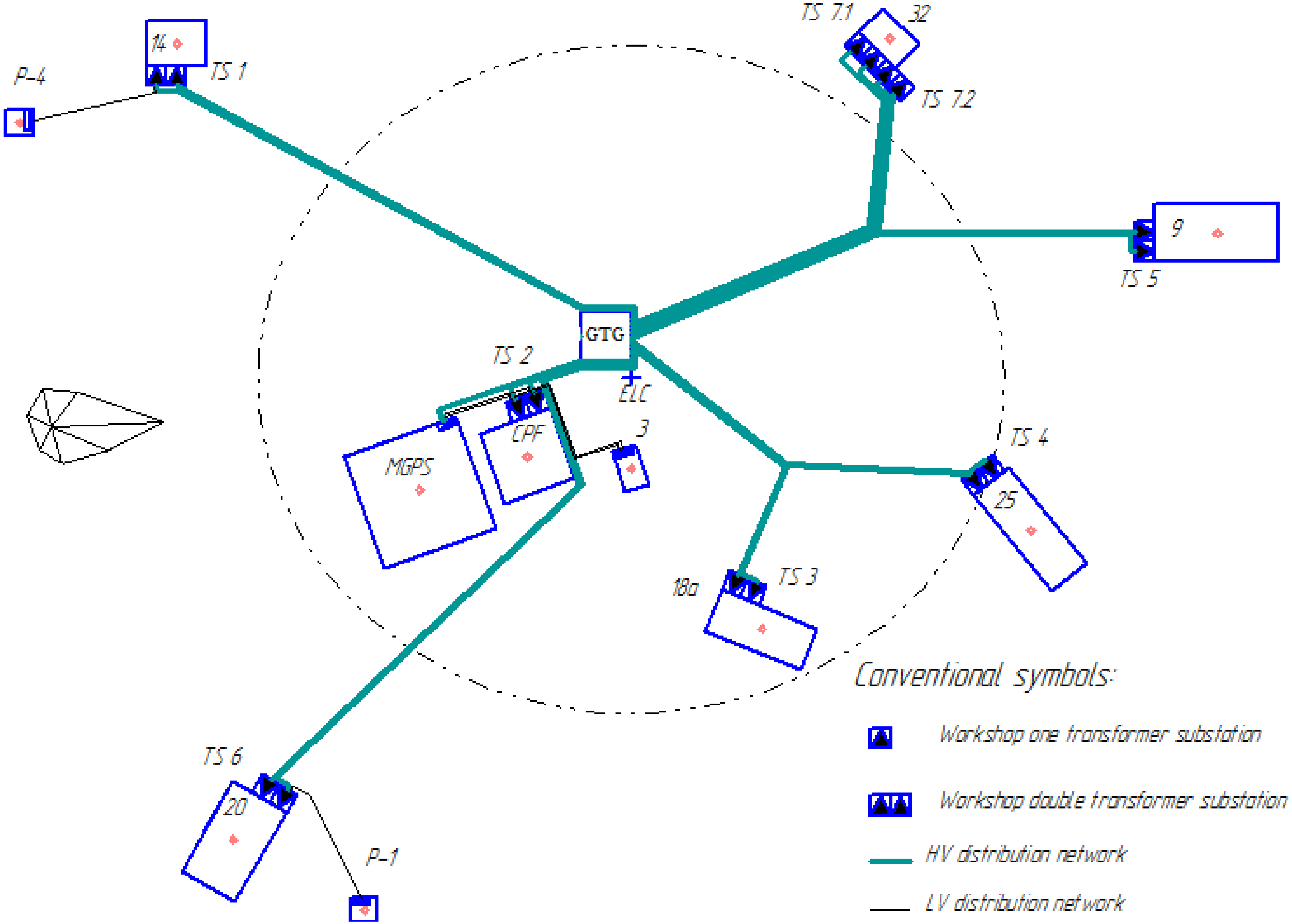

Figure 2.14. Autonomous power supply system general layout

3. Economic data evaluation, financial criteria calculation

3.1 Inputs calculation for economic model

For the economic evaluation of the project, the net present value (NPV) is used. For the comparison of projects, values of minimum prices on electricity are calculated. The main components of economic model of the project are described below.

3.1.1 Investments calculation

The aim of this thesis is to evaluate different power supply systems for power generation in Krapivinskoe oilfield. That is why it was decided to calculate investments by using specific prices of equipment. Investment is defined as all economic items needed to carry out the accomplishment of the plant.

Centralized power supply system

Feeder line investments calculation:

$$\mathrm{C_{FL}} = \mathrm{c_{FL}} \cdot \mathrm{L_{FL}} \cdot \mathrm{k_{cond}} = 2822.1 \cdot 10 \cdot 1.053 = 27\ 716.7 \text{ ths. RUB}$$

where c_{FL} – specific cost of building overhead transmission line (up to 150 kV) with steel double-chain poles and chosen wire type, ths. RUB/km [19];

L_{FL} – feeder line length, km;

k_{cond} – scale-up factor, related to building area type, marshy ground area in our case [19].

For total cost calculation it is necessary to add costs for landscaping, temporary buildings and constructions, design and exploration works, other works and costs. Average values of the specified costs from basic cost: [19]

- 1,5% – landscaping;
- 3,3% – temporary buildings and constructions;
- 9,0% – design and exploration works and designer's service;
- 3,18% – support of construction management company service, construction compliance monitoring;
- 8,0% – other costs;
- 165 000 ths. RUB/km – clearance, forest aisle expenses;
- 800 000 ths. RUB/km – wood strip logging roads.

Annual feeder line loses cost:

$$\mathrm{C_{loses}} = \Delta\mathrm{W_{FL}} \cdot \mathrm{T_{cons}} = 155 \cdot 80 = 12\ 376 \text{ RUB}$$

where ΔW_{FL} – power loses, MWh;

T_{cons} – consumption tariff rate, RUB/MWh. [20]

The investment costs to feeder line are shown in the following table.

Table 3.1. Feeder lines costs summary table

Equipment	Type	Remarks	Cost parameter, ₽/km	Cost, ₽
Feeder lines	two 110 kV overhead lines AS–70/11 (10 km)	on steel double-chain pylons	2 971 671 ₽	29 716 713 ₽
	Landscaping	0,015	44 575 ₽	445 751 ₽
	Temporary constructions	0,033	98 065 ₽	980 652 ₽
	Design and exploration works	0,09	267 450 ₽	2 674 504 ₽
	Support of construction management company service, construction compliance monitoring	0,0318	94 499 ₽	944 991 ₽
	Other costs	0,08	237 734 ₽	2 377 337 ₽
	Clearance, forest aisle expenses		165 000 ₽	1 650 000 ₽
	Wood strip logging roads		800 000 ₽	8 000 000 ₽
	Total investment			**46 789 948 ₽**
Feeder lines loses	155 MWh	80 ₽		12 376 ₽

Main step-down substation investment cost: [19]

$$C_{MSS} = 47\ 918 \text{ ths. RUB}$$

For calculation of total cost of substation building, it is necessary to add other costs, which have been calculated from basic cost using following percentage rates:

- 5,0% – mobilization works;
- 4,0% – landscaping;
- 3,9% – temporary buildings and constructions;
- 8,5% – design and exploration work and designer's service;
- 3,18% – support of construction management company service, construction compliance monitoring;
- 8,5% – other costs. [19]

Annual feeder line loses cost:

$$\text{C}_{\text{loses MSS}} = \Delta\text{W}_{\text{MSS}} \cdot \text{T}_{\text{cons}} = 95.1 \cdot 80 = 7\ 575 \text{ RUB}$$

where ΔW_{MSS} – power loses, MWh;

T_{cons} – consumption tariff rate, RUB/MWh. [20]

The investment costs to feeder line are shown in following table.

Table 3.2. Main step-down substation costs summary table

Equipment	Type	Cost parameter	Cost, ₽
Main step-down substation	two double-winding transformers: ТДН – 16000/110	47 918 000 ₽	47 918 000 ₽
	Mobilization works	0,050	2 395 900 ₽
	Landscaping	0,040	1 916 720 ₽
	Temporary constructions	0,039	1 868 802 ₽
	Design and exploration works	0,085	4 073 030 ₽
	Support of construction management company service, construction compliance monitoring	0,032	1 523 792 ₽
	Other costs	0,085	4 073 030 ₽
	Total		**63 769 274 ₽**
Transformer loses		95.1 MWh	7 575 ₽

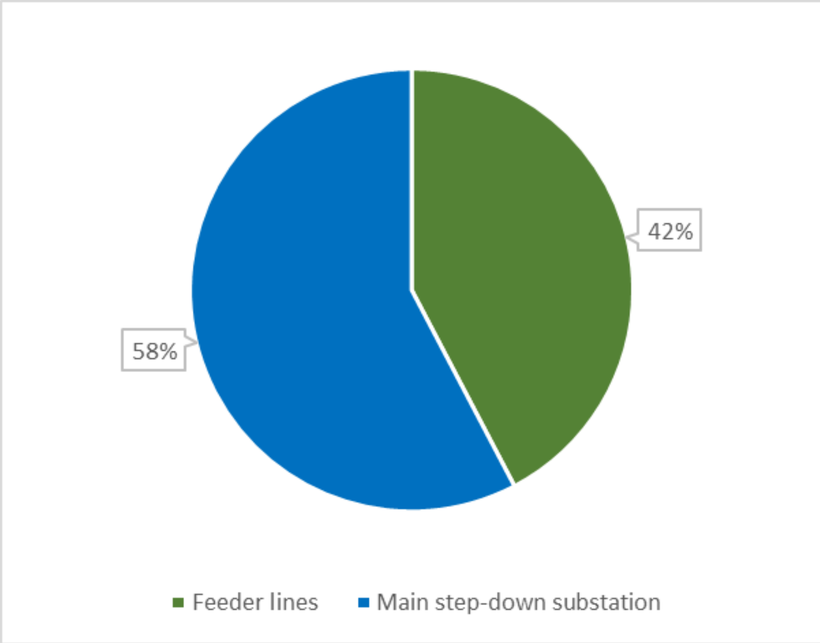

Figure 3.1. Centralized system investments

Total investment of centralized power supply system equals:

110 559 000 RUB

Autonomous power supply system

There are wide range of GTG installations in the market from domestic manufacturers to foreign ones. The prices fluctuation is observed within the boundaries of $ 250 and $ 800 for kW of installed capacity. The chosen GTG is produced by domestic manufacturing company – “OAO "REP Holding". The domestic manufacturer has been chosen thanks to the import substitution viewpoint, which becomes favorable among large industrial companies. JSC "REP Holding" is a Russian power engineering holding, which is dominating the field of manufacturing and supplying of the electrical equipment. The enterprise performs engineering design, manufacture and package supply of power and electrical equipment for gas, oil, power industry, especially for power generation and network integration.

In compliance of GTG installations manufacturing standard report [17], the concrete investment value for two GTG – 16 block-modular assemble with subsystems (UGT16000C type) is equal to 683 520 000 RUR on-key base, which amounts $ 356 per kW of installed capacity. The supplied installation is manufactured as block-modular set of units with advanced assembling readiness and quick commissioning, starting up ability. Upon the whole, purchasing of the installation is a complex process, which can be done in tender procedure, direct purchase, supply from preferred or cooperation company. Therefore, prices would differ, depending on the priorities of ordering customer and specific market situation.

Eventually, the investment value will be subjected to sensitivity analysis in fourth chapter to discover any changes due to price fluctuation.

Finally, investment in centralized and autonomous power supply systems equal 110.5 and 683.5 mln. RUB, correspondingly. The investment in autonomous PSS is around six times greater, the shares are shown on following diagram.

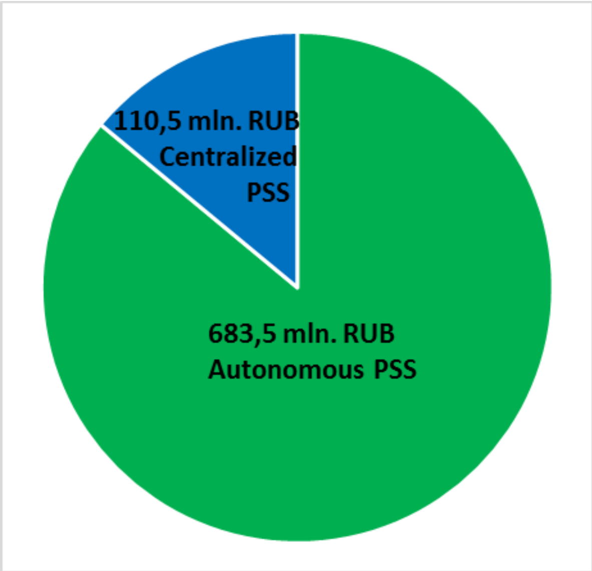

Figure 3.2. Investments in both variants

3.1.2 Depreciation

Depreciation is the decrease in value of the asset due to the passage of time. Depreciation is a method of cost allocation. Distribution of the costs can be based on different factors, but it is always connected with the estimated period, the product can generate revenue for the company, also known as the economic life of the asset. Only those items that get lost value over time may be depreciated. There are several types of depreciation, such as straight-line and accelerated depreciation.

The simplest and most commonly used method, straight-line depreciation, is calculated by taking the purchase or acquisition price of an asset, subtracting the salvage value (value at which it can be sold once the company no longer needs it) and dividing by the total productive years for which the asset can reasonably be expected to benefit the company (or its useful life). Example of the straight-line depreciation is shown on following figure [22]:

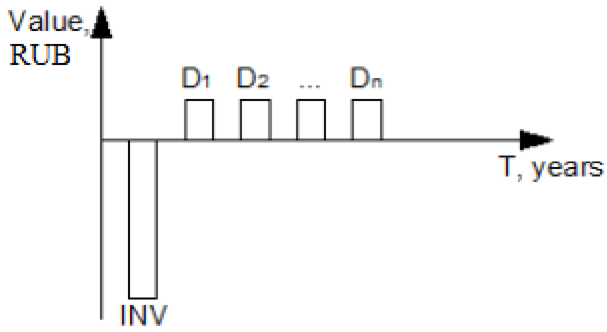

Figure 3.3. Straight-line depreciation

Depreciation is calculated using formula:

$$D = \frac{V}{T},$$

where V – value of the investment,

T – lifetime period. [22]

Example of calculation of depreciation for the 110 kV feeder lines to MSS is shown below:

Annual depreciation, calculated by formula:

$$D = \frac{C_{FL}}{T} = \frac{46\,790\,000}{32} = 1\,462\,000\ RUB$$

3.1.2 Expenditures calculation

Centralized power supply system

Connection to the grid fee

It is strictly obligated by government and The System Operator of the Unified Power System in Russia (SO UPS) to pay fees for connection to the grid in case of centralized power supply system. Conditions of networks accession shall provide:

- The technical requirements concerning accession;
- Amount of electricity ordered and works performance terms for accession to the network;
- Location of accession points to networks;
- The list of the rendered services and tariff conditions;
- Cost of services and payments procedure for them.

In view of the above and based on regulatory documentation of SO UPS [21], cost of connection to the grid includes fees for:

- Technic specifications preparations, C_{TSP} = 213 RUB/kW;
- Abiding check procedures, C_{ACP} = 80 RUB/kW;
- Energy and equipment audit, C_{EEA} = 62 RUB/kW;
- Connection and maintenance, C_{CM} = 195 RUB/kW.

In terms of the equivalent amount of rated active power load (16.188 MW) observe:

- Technic specifications preparations, C_{TSP} = 3 455 329 RUB;
- Abiding check procedures, C_{ACP} = 1 300 382 RUB;
- Energy and equipment audit, C_{EEA} = 1 005 275 RUB;
- Connection and maintenance, C_{CM} = 3 149 861 RUB.

Total fee for connection to the grid: C_{GC} = 8 910 846 RUB.

Electric power consumption charges

The Federal Tariff Service of Russia decrees the methodical instructions for calculation of electricity tariffs in the retail/consumer market, which says that differentiation on several groups of tariffs for an electrical energy has to be provided. In the enterprise, the double-rate tariff is applied. It comprises variable and fixed rates. Variable is a bid price and cost of services which reflects consumption of power from electric network. The constant is a fixed payment for electric power of the enterprise.

- Tariff for power, T_{POWER} = 560 325 RUB/MW;
- Tariff for consumption, $T_{CONS.}$ = 80 RUB/MWh. [20]

Calculated charges:

$$C_{POWER} = T_{POWER} \cdot P_R = 560\ 325 \cdot 16.188 = 9\ 070\ 537 \text{ RUB;}$$

$$C_{CONS.} = T_{CONS.} \cdot P_R \cdot T_m = 80 \cdot 16.188 \cdot 7500 = 9\ 675\ 163 \text{ RUB.}$$

where P_R - rated active power load, MW;

T_m – maximum load utilization time, h.

Total charge for electricity consumption:

$$C_{EC} = C_{POWER} + C_{CONS.} = 18\ 745\ 700 \text{ RUB}$$

Environmental fees for APG burning

The APG, extracting together with crude oil, is burned out on flares and fees for environment polluting are payed. The following table shows the percentage of APG components and specific fees for pollution by each of them. We will take into account only difference in the amount of APG burned, between centralized and autonomous power supply systems, because there is no sense for projects decision making in calculating whole volume of APG extracted and burned. The difference is equal to fuel consumption of GTG installations. The fees for each component were calculated multiplying percentage of composition by total amount and fee tariff.

Table 3.3. Environment pollution fees summary table [23, 24]

APG component part	Percentage of composition	Fee tariff, RUB/t	Calculated fee, RUB
CH_4	0,90	108	3 122 882 ₽
C_2H_8	0,03	47,5	45 783 ₽
C_2H_6	0,02	1,6	1 028 ₽
N_2	0,02	138,8	89 188 ₽
CO_2	0,03	1,6	1 542 ₽
%	100	**Total (annual)**	**3 260 424 ₽**

Feeder lines maintenance costs

Standard repair and maintenance costs of electric facility - the monetary value, which is necessary and sufficient to perform repair work of equipment in planned year on the nomenclature standard, established by:

- Rules for the organization of maintenance and repair of equipment, buildings and structures of power plants and networks;
- Technical and economic standards of the planned preventive repair;
- Operational and repair documents for concrete types of equipment.

Overhead lines of 110 kV, AC type are required to have maintenance every five years; also, total overhaul should be held ten years periodically. As it is considered in "Standard rates of repair costs as a percentage from book value of specific types of the property, plant and power plants equipment”, percentage rate for maintenance – 0.25 %, for total overhaul – 0.4 %.

$$C_{FL.M.} = r_{FL.M.} \cdot C_{FL} \cdot k_R = 0.0025 \cdot 29\,716\,713 \cdot 1.3 = 96\,579 \text{ RUB};$$

$$C_{FL.O.} = r_{FL.O.} \cdot C_{FL} \cdot k_R = 0.004 \cdot 29\,716\,713 \cdot 1.3 = 154\,527 \text{ RUB};$$

where $C_{FL.M.}$ – feeder lines maintenance cost, RUB;

$C_{FL.O.}$ – feeder lines overhaul cost, RUB;

$r_{FL.M.}$ – percentage rate for maintenance;

$r_{FL.O.}$ – percentage rate for overhaul;

C_{FL} – feeder lines cost, RUB;

k_R – regional coefficient, reflecting the Extreme North regions. [18]

Main step-down substation maintenance costs

Based on [18], for chosen substation type the percentages for maintenance and overhaul corresponding are 1.21 % and 2.49 %. Maintenance should be held each three years and overhaul on 9th years basis. Thus, obtain:

$$C_{MSS.M.} = r_{MSS.M.} \cdot C_{MSS} = 0.0121 \cdot 47\,918\,000 = 575\,808 \text{ RUB};$$

$$C_{MSS.O.} = r_{MSS.O.} \cdot C_{MSS} = 0.0249 \cdot 47\,918\,000 = 1\,193\,158 \text{ RUB};$$

where $C_{MSS.M.}$ – main step – down substation maintenance cost, RUB;

$C_{MSS.O.}$ – main step – down substation overhaul cost, RUB;

$r_{MSS.M.}$ – percentage rate for maintenance;

$r_{MSS.O.}$ – percentage rate for overhaul;

C_{MSS} – main step – down substation cost, RUB.

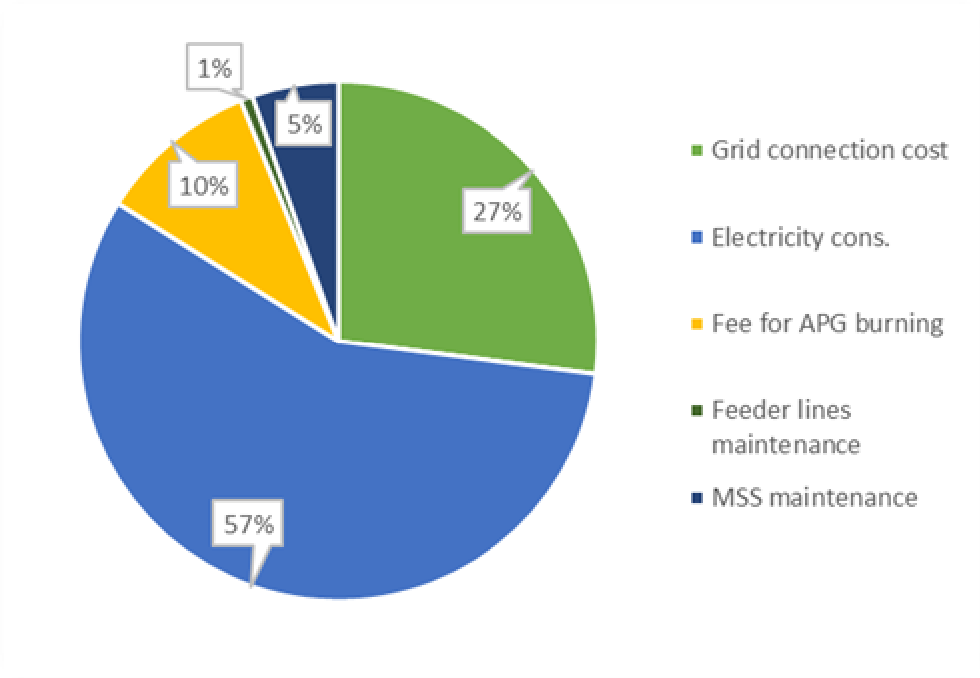

Figure 3.4. Centralized system expenditures

Autonomous power supply system

Maintenance and overhaul

According to [10], the lifetime of the installation is 200 000 hours, maintenance should be performed each 25 000 hours, overhaul each 60 000 hours. Having recalculated the quantity of hours to numbers of years, using time of maximum power utilization, obtain following results: maintenance and total overhaul must be performed each 3 and 8 years corresponding.

The maintenance and overhaul costs generate corresponding 5 and 10 % from total investment, which are values of 30 758 400 and 68 352 000 RUB, single time operation. [18]

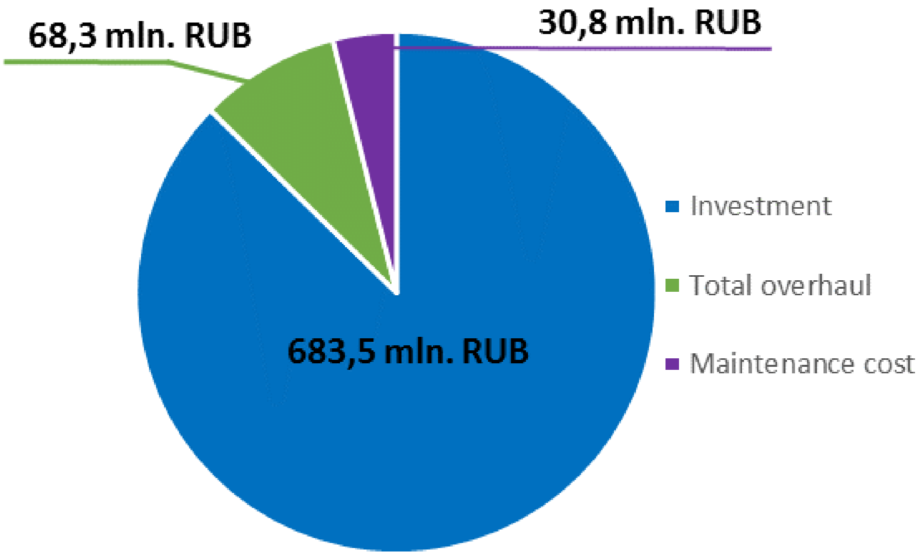

Figure 3.5. Autonomous system monetary indicators

Virtual fuel cost (regarding to APG consumed volume)

$$C_{APG} = c_{mining} \cdot V_{APG} = 250 \cdot 46\,090 = 11\,522\,450 \text{ RUB}$$

where c_{mining} – cost of APG mining (internal cost of the enterprise), RUB/ths. m^3 [25]

V_{APG} – annual APG consumption for purpose of generating electricity, ths. m^3.

Actually, the enterprise does not pay for this APG as a GTG installations fuel, but cost should be calculated, because oil and gas extracting enterprises spend money to mine it simultaneously with oil as undesirable component of crude oil. It is proved, that the higher the well-pad saturation of APG, the higher the variable cost of oil production.

3.1.3 Escalation rates determination

Nowadays, the *inflation rate* (r_{inf}) has achieved 4.3 %. Comparing with previous year, the decrease is equal to 3.4 % and the reduction tendency has been observing. [26]

Figure 3.6. Inflation rate in Russia, 2012 – 2017

In the considerable future, the rapid reduction of inflation has expected 5.5 % and 4 % in 2017 and 2020 years corresponding. Inflation rate decrease, to the specified values, achieves by ramping-up in rate of economic growth and organizational policy development. Firstly, strict policy, regarding regulated tariffs for infrastructural fields, has been achieving. Secondly, measures, for goods and services supply gaining, competition promotion, anti-inflationary policy, have been performing. In long term, the inflation rate has considered 5.3 % by 2025 year. [27]

In addition, the duration of the projects is estimated as 32 years, keeping inflation at exact 5.3 % for lifetime years is not possible. Therefore, taking into account worse forecast, accept 6% of inflation rate. Moreover, it will be subjected to sensitivity analysis.

The *real rate* (r_{real}) has assumed as desired minimal rate with allowance for risk. Desired minimal rate is a minimum rate earned by an investment, which will induce to put money into a bank or government bonds (5 % - 10 %). In view of the above, the real rate has accepted equal 8 %. [28]

The *discount rate* (r_{nom}) is calculated by the Fisher's formula [22]:

$$r_{nom} = (1 + r_{inf}) \cdot (1 + r_{real}) - 1 = (1 + 0.06) \cdot (1 + 0.08) - 1 = 0.1448$$

The *income corporate tax* (T_c) for organizations in Russian is equal to 20% according to the Tax Code of the Russia Federation [29].

Weighted average costs of capital (WACC)

To calculate the effects of financing, we use the weighted average cost of capital (WACC) concept. The WACC is the minimum return that a company must earn on an existing asset base to satisfy its creditors, owners, and other providers of capital, or they will invest elsewhere. The WACC is calculated taking into account the relative weights of each component of the capital structure [22].

$$r_{WACC} = r_{equity} \cdot \frac{E}{E+D} + r_{debt} \cdot \frac{D}{E+D} \cdot (1 - T_c),$$

where r_{equity} – own capital rate of return;

r_{debt} – rate of interest set by bank, %;

E – share of equity in the capital structure;

D – share of debt in capital structure;

T_c – corporate tax rate.

This WACC model is implemented, if project is financing by loan. It is necessary to apply the interest rate at which the bank provides loans to large companies, to use the WACC model.

The rate of *bank interest* (r_{debt}) is set equal 14.15 %, according to data from Central Bank of Russian Federation for entrepreneurial need loans with time limit for repayment more than one year. [30]

The *escalation rate of electricity price* assumption is a difficult procedure; moreover, the rate cannot be predicted with the needed accuracy for the project. However, electricity prices would be raised more than 4 %, but not higher than inflation rate. [11]. Therefore, it is set equal to 6 %, taking into account worse case of electricity market developing.

3.2 Financial criteria evaluation

Net Present Value calculation

The net present value is a sum of cash flows of the business, which are equilibrated to present time, taking into account the discount rate; in other words, sum of discounted cash flows. [22]

During steps of cash flows calculation, the earnings before tax (EBT), tax shield, earnings after tax (EAT) were calculated. Principally, both variants are not considered to have revenues, thus, calculations are free of revenues component.

Earnings before tax are calculated by the following formula:

$$\mathrm{EBT}_t = -C_t - \mathrm{D}$$

where $\mathrm{C_t}$ – total cost in 't' year, RUB;

D – depreciation. RUB.

Costs of the centralized PSS include grid connection, electricity consumption, APG burning penalties, maintenance and overhaul of feeder lines and main step-down substation. For the autonomous PSS they are GTG installation maintenance and overhaul costs, loan interest (in case of external financing of the investment). Other presumable and potential costs are considered as identical for both variants (for instance: employees salaries) and they do not effect on decision-making procedure and result, therefore they are not included in economic model.

Tax shield calculation:

$$\mathrm{Tax_t} = \mathrm{EBT_t} \cdot \mathrm{T_c}$$

where $\mathrm{T_c}$ – corporate tax rate.

In the instant case of enterprise, there are other revenues (not connected to these projects) and costs from these projects will lead to less total tax amounts of the company. It means, that we calculate tax shield as negative and EAT would be higher on tax amount.

Earnings after tax are calculated according to the formula:

$$\mathrm{EAT_t} = \mathrm{EBT_t} - \mathrm{Tax_t}$$

Finally, cash flows are defined considering the equation:

$$\mathrm{CF_t} = \mathrm{EAT_t} + \mathrm{D} - \mathrm{PMT_t}$$

where PMT_t – loan principal payment, RUB (in case of external financing of the investment in the autonomous PSS variant).

Model calculations generate following cash flows:

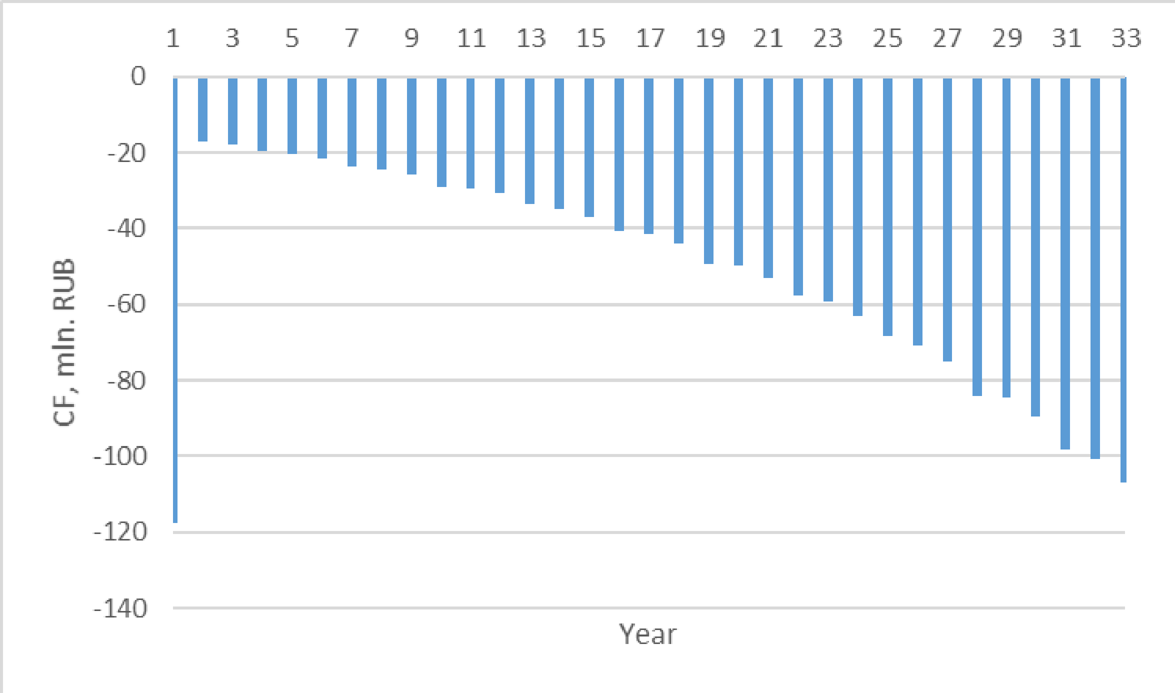

Figure 3.7. Centralized power supply system cash flows

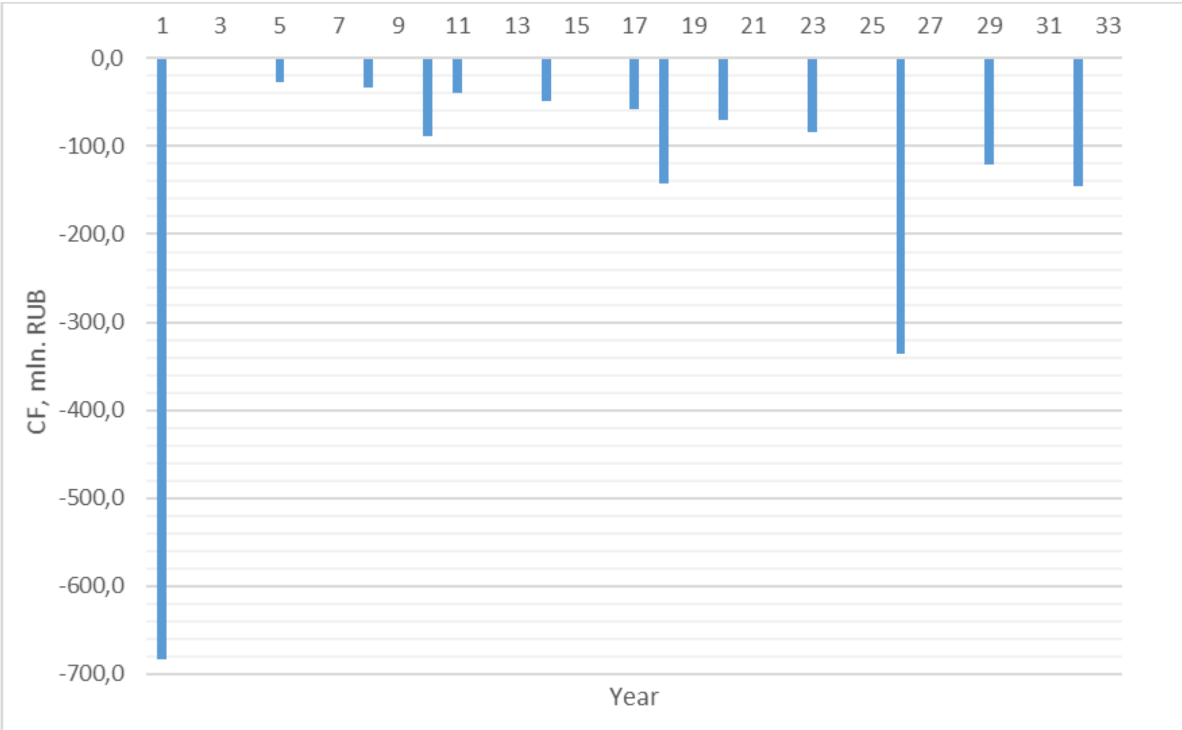

Figure 3.8. Autonomous power supply system cash flows

It is apparent, that cash flows in case of centralized PSS are smoothly apportioned, because of almost identical costs through years, inclusive of escalation rates. In contrast, the autonomous PSS reflects heterogeneous in time cash flows, which include maintenance and overhaul of GTG installation, taking into account the time value of money. The cash flow in the year twenty-five is the biggest one, due to maintenance and overhaul occurring in the same year.

The Net Present Value is calculated according to the formula:

$$NPV = \sum_{t=1}^{N} \frac{CF_t}{(1 + r_{nom})^t} - INV$$

where CF_t – cash flow in 't' year, RUB;

r_{nom} – discount rate, %;

N – lifetime of the project, years;

INV – investment made in '0' year, RUB.

NPV values are provided in the following table:

Table 3.4. NPV values summary table

Power supply system variant	NPV, mln. RUB
Centralized	- 305.5
Autonomous	- 783.5

As it is seen from results, NPV of the second variant of PSS is more than two times lower, mainly due to predominate investment in the project. Furthermore, cash flows of the second variant in other years are dominating, comparing with centralized system. Calculation was performed without external financing of the second variant; this opportunity will be discussed further.

In case of external financing of the second variant, considering that a company borrows 80 % of investment value from the bank, observe following financial data:

Table 3.5. Investment structure

Loan ratio to investments, %	80
Loan, RUB	546 816 000
Annual payment, RUB	89 694 997
Own fonds, RUB	136 704 000

The repayment period is 15 years, the debt repayment plan:

Table 3.6. Debt repayment plan

Year	Loan balance, RUB	Principal payment, RUB	Interest payment, RUB	Total payment, RUB
1	546 816 000	12 320 533	77 374 464	89 694 997
2	534 495 467	14 063 888	75 631 109	
3	520 431 580	16 053 928	73 641 069	
4	504 377 652	18 325 559	71 369 438	
5	486 052 093	20 918 625	68 776 371	
6	465 133 467	23 878 611	65 816 386	
7	441 254 856	27 257 434	624 37 562	
8	413 997 422	31 114 361	58 580 635	
9	382 883 061	35 517 043	54 177 953	
10	347 366 017	40 542 705	49 152 291	
11	306 823 312	46 279 498	43 415 499	
12	260 543 814	52 828 047	36 866 950	
13	207 715 767	60 303 215	29 391 781	
14	147 412 552	68 836 120	20 858 876	
15	78 576 431	78 576 431	11 118 565	

The following diagram reflects cash flows of the project financed by debt:

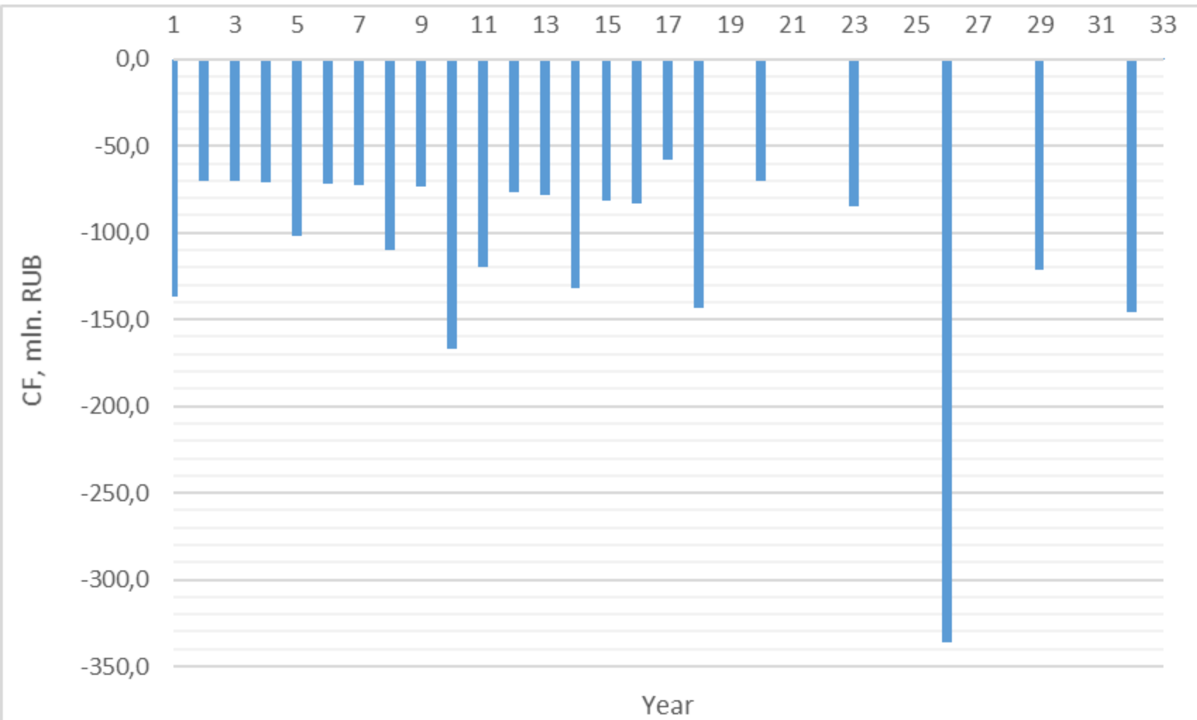

Figure 3.9. Autonomous power supply system cash flows in case of 80 % external financing

In such a circumstance, NPV of the second variant equals - 698.7 mln. RUB, almost 100 mln. RUB higher than in case of internal financing. Nevertheless, investment financing combinations and corresponding results will be provided in sensitivity analysis chapter; final discussion and decision-making will be performed after sensitivity analysis as well.

Virtual electricity minimum price calculation

The virtual minimum price can be calculated in two ways: with purpose of selling and without one. This price include investments, all costs within the lifetime period. Evaluation of these prices allows projects comparing.

The internal virtual electricity prices were calculated as:

$$C_{\min} = \frac{\mathrm{NPV}}{\mathrm{PVAF} \cdot \mathrm{W_{year}}} = \frac{NPV}{\frac{1-(1+r_{nom})^{-N}}{r_{nom}} \cdot W_{year}}$$

where PVAF – present value annuity factor;

r_{nom} – discount rate, %;

N – project lifetime, years;

W_{year} – annual electricity consumption/production, MWh.

The virtual electricity prices for selling purpose were calculated as:

$$C_{\min} = \frac{\mathrm{NPV}}{\mathrm{PVAF} \cdot \mathrm{W_{year}}} = \frac{NPV}{\frac{1-(1+r_{nom})^{-N}}{r_{nom}} \cdot W_{year} \cdot (1-T_c)}$$

Table 3.7. Electricity minimum prices summary table

Power supply system variant	Virtual internal C_{min}, RUB/MWh	
	Internal	For selling
Centralized	370	460
Autonomous	950	1 180

4. Sensitivity analysis and decision-making conclusion

4.1 Influence of investment on NPV

Investment value has a crucial influence over NPV in both variants; therefore, the sensitivity analysis on this parameter should has been done. Moreover, it would be a splendid opportunity to find the cross point between two dependence lines.

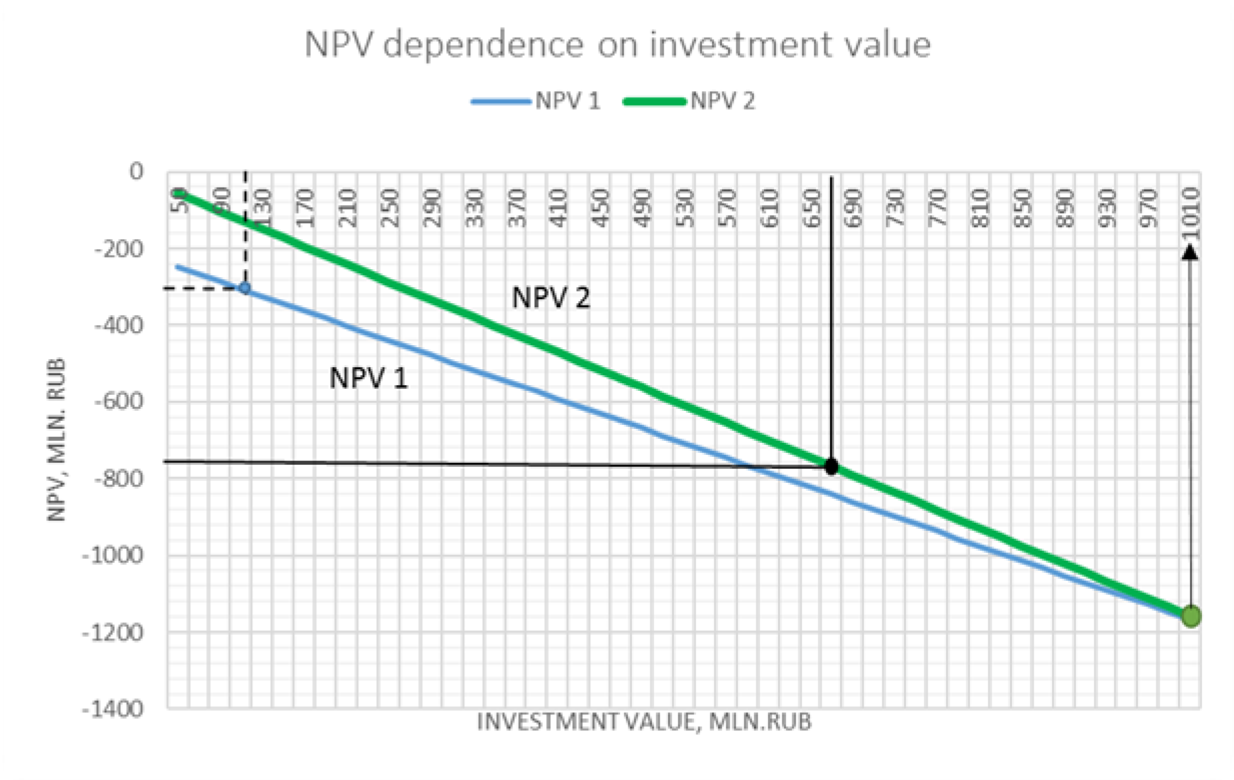

Figure 4.1. NPV dependence on investment

Primarily, NPV 1 line refers to NPV of centralized power supply system, NPV 2 line to autonomous system. It is evident, that NPV 2 is laying upper than NPV 1, but due to greater investment, current value of NPV 2 is much lower. If investment in the first variant attains 590 mln. RUB, the NPV 1 value would be equal to NPV 2. However, the probability of this possibility is low. Considering NPV 1 separately, we can say, that practically it cannot be lower than - 600 mln. RUB, because investment in centralized PSS with similar characteristics could hardly be imagine higher 400 mln. RUB.

Speaking about NPV 2, the investment can easily fluctuate from 550 to 850 mln. RUB for such powerful set, depending on the market situation and manufacturer company of equipment, brand and assembling type of installation. Consequently, in the best-case scenario, NPV 2 would approximately be equal - 660 mln. RUB, in the worst one - 1 000 mln. RUB, considering only own capital financing.

The cross point is on the investment level of 1 000 mln. RUB. As I have said, for the first variant it is unattainable to have investment greater 400 mln. RUB; moreover, for the second variant the supply contract for similar power generation installation is obviously overvalued.

It can be concluded from the graph, that the NPV 1 is prevails the NPV 2, making provision for different scenarios of investment values fluctuation.

4.2 Influence of discount rate on NPV

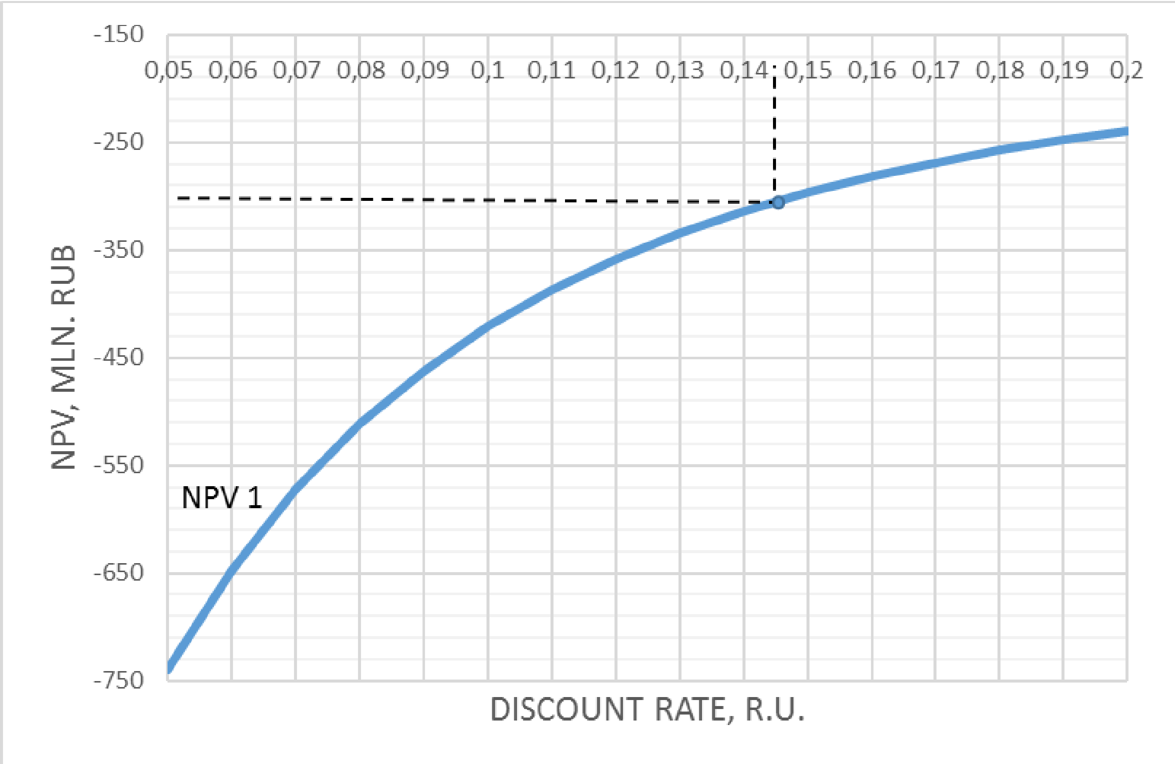

Figure 4.2. NPV 1 dependence on discount rate

The NPV is more sensitive to discount rate at the beginning of the curve, when discount rate is no more than 10 %. After passing the 10 % point, NPV becomes less sensitive, the growth of NPV curve declines. Important notice, that discount rate reduction will reduce NPV largely, but increase in discount rate will increase NPV to a lesser extent. In the context of current assumption on discount rate, it can vary within the scope of ± 2.5 % in long run prospective [26]. Consequently, NPV can vary from - 350 mln. RUB to - 270 mln. RUB from current position.

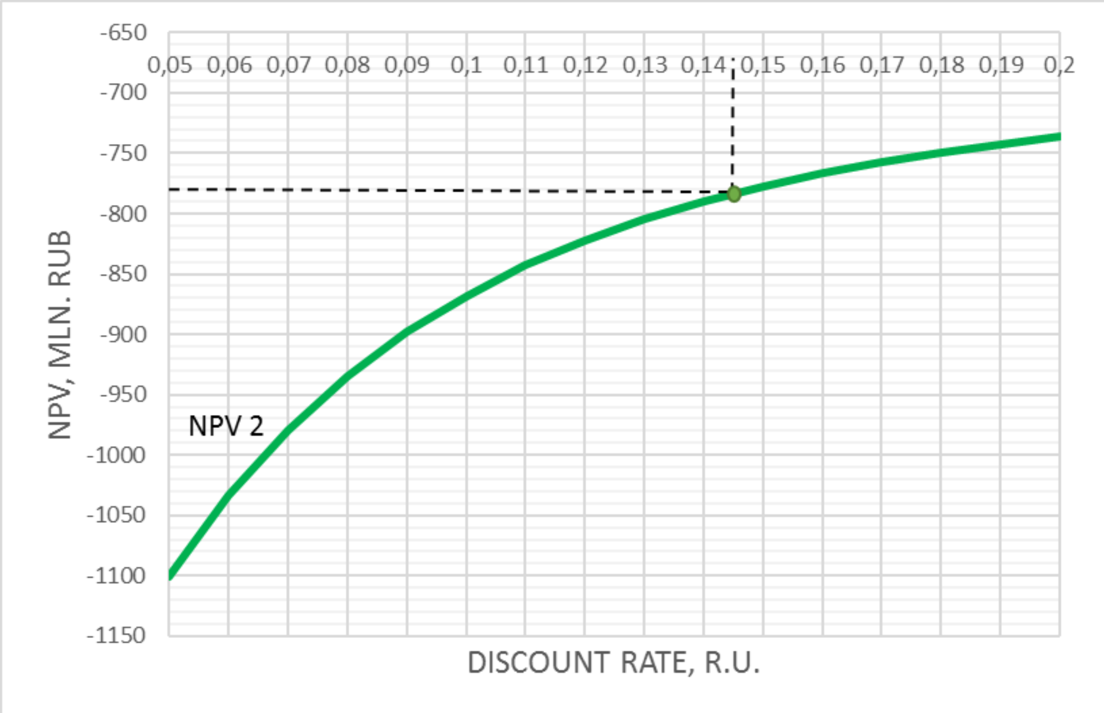

Figure 4.3. NPV 2 dependence on discount rate

The analogous characteristic is shown on this graph. Within frames of ± 2.5 % in discount rate change, the NPV possess a value from - 825 mln. RUB to – 760 mln. RUB, consequently. Whatever the discount rate, the NPV 1 is higher than the NPV 2; sensitivity analysis on discount rate is generally intended for separate evaluation of NPV in both variants.

4.3 Influence of electricity price on NPV

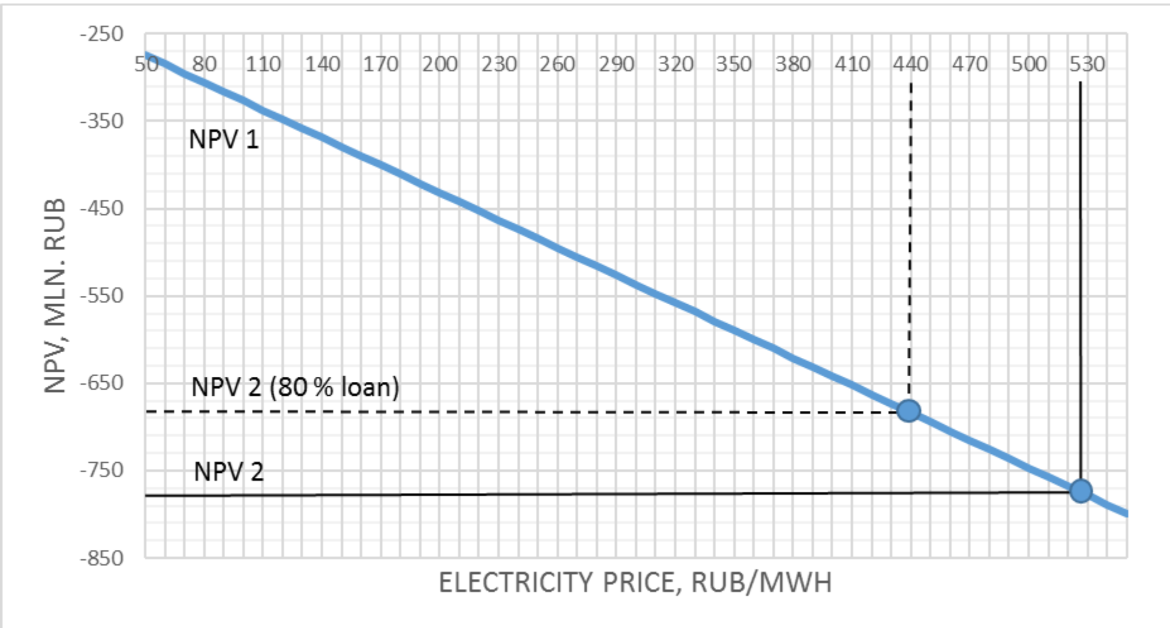

Figure 4.4. NPV 1 dependence on electricity price

Basically, the electricity price fluctuation has only impact on centralized PSS, because of purchasing electricity need, thus the sensitivity analysis has been performed only for first variant of power supply. The current tariff for energy consumption is 80 RUB/MWh and 560 325 RUB/MW for installed power, meaning that total price with the project installed power and consumption amount is 154 RUB/MWh (purchasing at 110 kV voltage level). The increase almost in three times in electricity price will lead to NPV equal NPV of the second variant with 80 % loan financing, and if the electricity price reaches 530 RUB/MWh, the NPV would be around - 770 mln. RUB (NPV 2).

Practically, electricity prices are growing nowadays, but it hardly can be established the price to be three times greater than 154 RUB/MWh in ten years prospective. In case of purchasing at lower voltage level, tariffs will be higher and of course, the NPV 1 can reach NPV 2. However, the change in voltage level will lead to change in whole system: different types of equipment, different investments and operational costs.

Summing up, buying electricity under soaring prices is still more economically feasible solution, until the price raised to 450 RUB/MWh.

4.4 Influence of external financing share on NPV

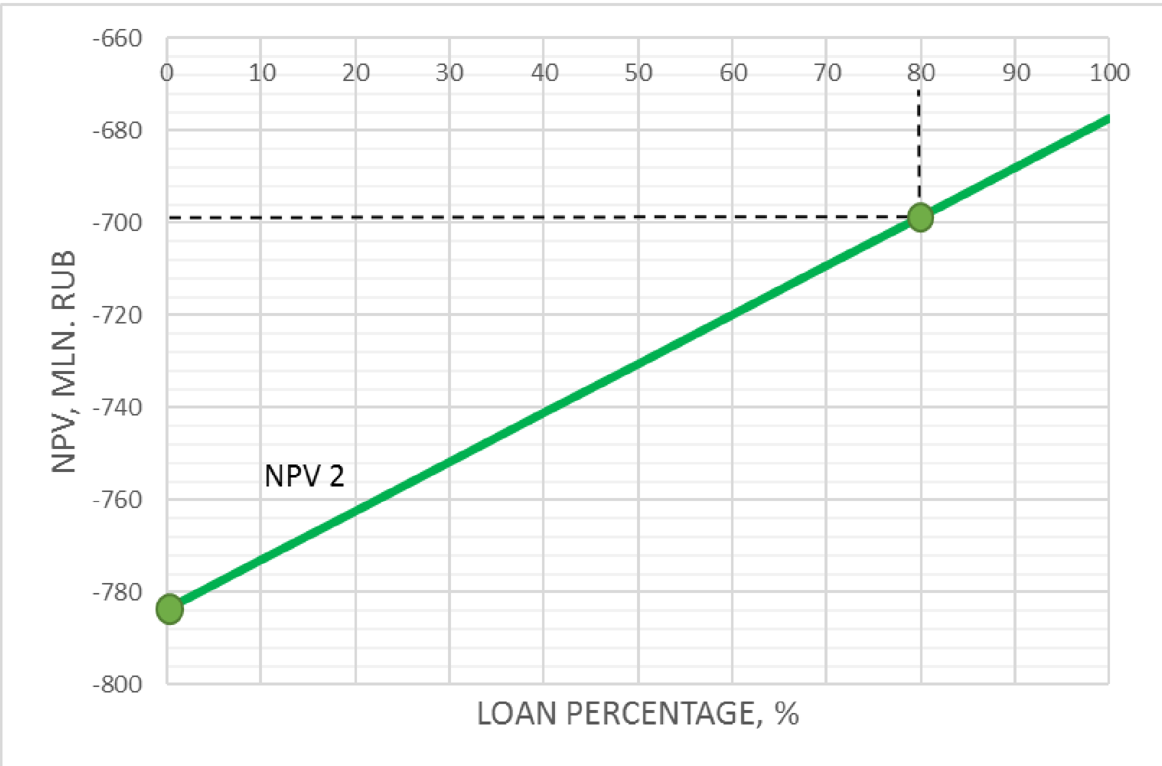

Figure 4.5. NPV 2 dependence on external financing share

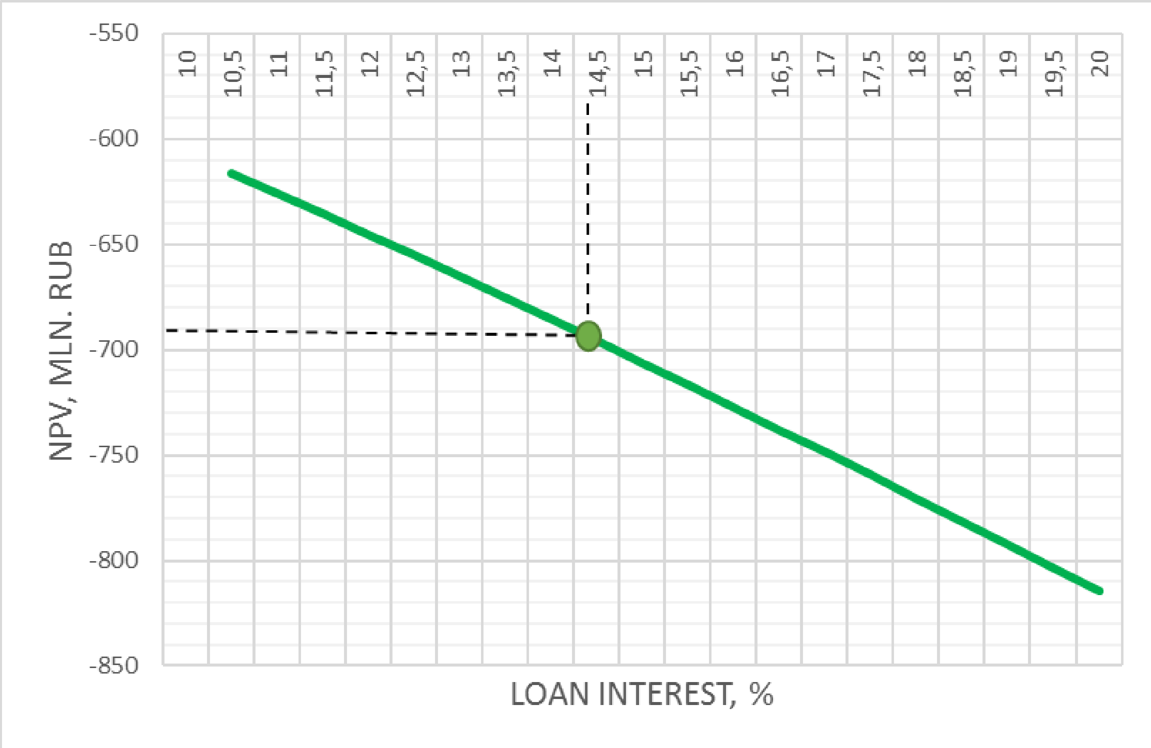

Figure 4.6. NPV 2 dependence on loan interest

It is considered in the second variant to have external financing opportunity and as the dependence graph shows, the more loan share of investment, the higher the NPV. According to official financial report of the enterprise [31], the long term borrowings of the company equal 2,4 bln. RUB, current assets are 3 bln. RUB, therefore a loan for 100 % of investment would constitute 0.03 % from whole borrowings of the company.

The company is solvent enough to take out a loan for investment coverage. Another question is that whether bank would be capable of landing whole amount. Anyway, the NPV value can be determined from the graph, depending on loan share. Based on the experience, the company was financed by different banks on amounts which several-fold higher than investment, observed in this project. For this reason, we can say, that the best value of NPV is - 677.5 mln. RUB.

4.5 Influence of APG burning penalties on NPV

One of the most urgent parameters, which influences to NPV 1, is associated petroleum gas burning penalties. The centralized PSS model include such costs as distinct from autonomous PSS. The Decree of the Government of the Russian Federation (*Regulation of 13.09.2016 n 913 about payments rates for negative impacts on the environment and additional coefficients [24]*), which set new increase coefficients for over limit pollutions, is going to be adopted by 2020. It is said in the regulation, that increase coefficient of 25 would be applied for over limit pollutions.

Other circumstance is that the required APG utilization factor equal 95 %, meaning that each cubic meter of burned APG above 5 % of recoverable gas, would cost 25 times higher. In light of aforementioned, the analysis on this factor has to be done.

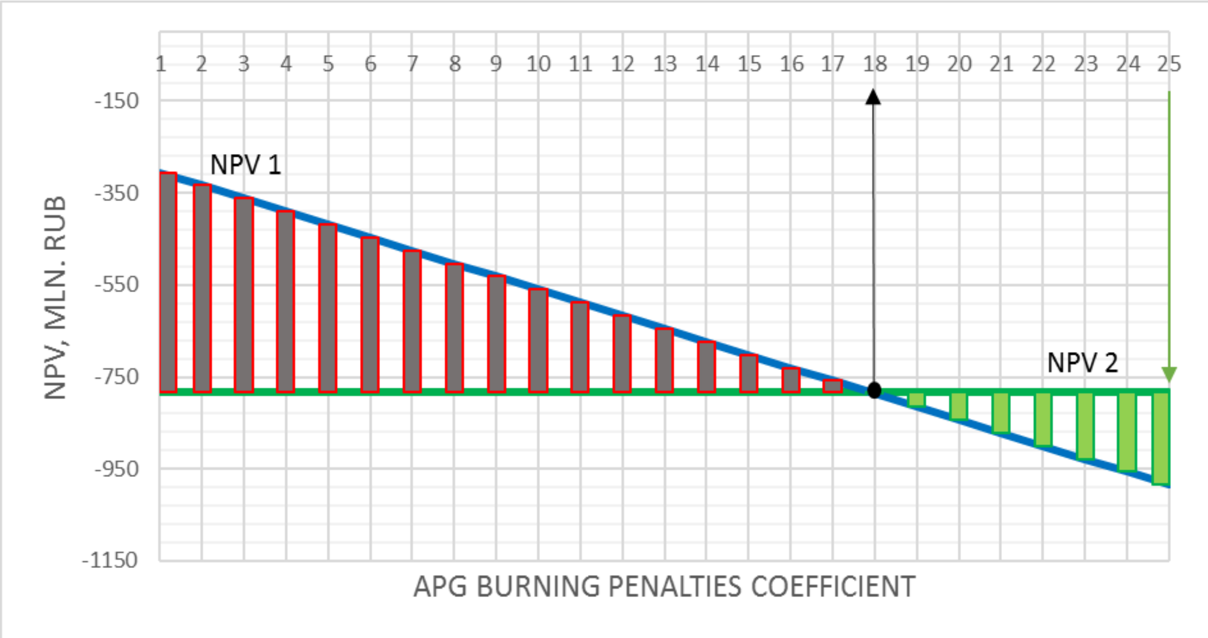

Figure 4.7. NPV dependence on APG burning penalties increase coefficient

As it is seen from the graph, upon reaching the increase coefficient of 18, the cross point is observed and NPV 2 becomes greater than NPV 1. Taking into account the governmental regulation, increased coefficient would be equal to 25; therefore, the difference between NPVs would be 200 mln. RUB in favor of autonomous PSS variant.

Nevertheless, the whole volume of burned APG and APG utilization factor, in the particular case, should be considered in the process of penalties evaluation and final decision making. In our situation, only the APG volume of fuel consumption of GTG installation was considered as APG burned volume in the first variant. Therefore, concluding above mentioned, if the volume of APG, used for power generation in the second variant, would be over limit pollution in the first variant, the NPV 2 would be higher by 2020 and the project of autonomous PSS will be economically feasible.

This way of APG utilization factor increase can simultaneously solve at least two issues: high penalties for pollutions and power supply of industry with high reliability and energy self-sufficiency.

Conclusion

According to the task guideline, the evaluation of centralized and autonomous power supply systems in oil and gas industry has been performed by author of the diploma thesis. Primarily, the theoretical foundation of power supply systems, implemented in oil and gas mining industry, has been provided with investigation of electrification problems in extreme north areas. The author has defined the oil field urgent problem of associated petroleum gas utilization and offered the solution approach.

In consequence of author's personal contribution, calculations of external power supply systems in both variants have been performed in technical part. Daily load diagrams, annual load duration diagram have been plotted for further computation. This part provides type selection, characteristics examination of feeder line, main step-down substation of enterprise for the centralized power system. Besides, calculations include the evaluation of gas turbine installations, according to enterprise rated power and recommended generation units load factor. The gas turbine set specifications, performance curves were provided and fuel consumption characteristics were calculated. Ultimately, external power supply systems general layouts have been plotted, specifying workshops, cables and workshops substations placing, and location of main step-down substation or gas turbine generator installation.

The economic part contains investments determination for both systems: 110.6 mln. RUB for the centralized system and 683.5 mln. RUB for autonomous one; depreciation, expenditures, financial criteria calculation. The net present values for both variants are -305.5 mln. RUB and -783.5 mln. RUB for centralized and autonomous systems, correspondingly. It is seen that higher investment leads to lower net present value and in the second variant, the investment is extremely high in comparison to first one. Finally, the sensitivity analysis on main inputs has been provided by author. It should be noted, that values of investment and associated gas burning penalties have more significant influence on the net present value.

The following recommendations are provided by author, based on obtained results and professional experience. The final decision-making could be undertaken regarding to several factors and the economic viability is not the crucial one. Firstly, the opportunity for connection to the grid should be considered: if the oil field is located in remote isolated area and there is no such an option, there is the only choice in favor of autonomous power system.

Secondly, the urgent role plays the associated petroleum gas utilization factor: if it is lower than 95 percent, the additional increasing rate for associated petroleum gas burning penalties would be applied, and the value is 25 by 2020. In conformity with sensitivity analysis, the autonomous system will be economically feasible if the rate is equal or higher than 18. Above mentioned fact means that it would be reasonable to utilize the gas, providing with electricity whole oil field and increase the level of associated gas utilization.

Moreover, the reliability of power supply is a key aspect for oil extracting industries and an autonomous power supply system can reach higher reliability indicators, high startup ability and operating flexibility. In addition, such block modular installations are not used on the same well site during whole lifetime, they are moving to another well pad after previous is finished, therefore, it will be reliable to use the same installation, instead of building new branch of feeder line and replacing the substation.

However, under current circumstances and assumptions, the variant of centralized power supply system is economically feasible, taking into account main economic indicators. To provide the strict recommendation, it is necessary to know the amount of the associated petroleum gas burning in the enterprise and then observe the associated petroleum gas utilization factor.

Forward looking, after 2020th year the associated petroleum gas burning penalties coefficient increase of 25 would be applied in case of burning more than 5 percent in associated petroleum gas by the law. Thanks to that fact, the autonomous power supply system will be the way of solving this issue. Furthermore, this variant would be feasible from economic viewpoint.

At the current moment, the centralized power supply system is favorable variant for power supply, if associated petroleum gas utilization factor is greater than 95 percent, if not, the enterprise should look forward to higher penalties after 2020 to the side of autonomous power supply system.

Bibliography and references

[1] ABRAMOVICH B. *Energosberezhenie neftegasovykh predprijatij: uchebnoe posobie. Oil and gas industries power supply: study guide.* Saint-Petersburg: SPb, 2008.

[2] KLIMOVA G. *Energosberezhenie na promishlennyh predprijatijah: uchebnoe posobie. Energy efficiency of manufacturing enterprises: study guide.* Tomsk: TPU, 2014.

[3] NIEMI S. *Survey of modern power plants driven by diesel and gas engines.* Finland: Espoo, 1997.

[4] The shift project data portal. Available at: http://www.tsp-data-portal.org

[5] MEHERWAN P. *Gas Turbine Engineering Handbook. Fourth edition.* UK: Elsevier 2012.

[6] SHELDRAKE A. *Handbook of electrical engineering: for practitioners in the oil, gas, and petrochemical industry*. England: WILEY, 2003.

[7] BPC Group. *Energetika i elektrotehnika dlja neftegaza. Energy and electrical engineering for oil and gas*. Moscow: Power Systems, 2010.

[8] *Pravila Ustrojstva Elektroustanovok. Rules of Electrical Facilities Maintenance*. Novosibirsk: Sib. Publishing house, 2009.

[9] SUMOROKOVA L. *Elektrosnabzhenie promishlennyh predprijatij. Industrial enterprises power supply*. Tomsk: TPU, 2012.

[10] REPH Holding. *Gazoturbinnyie elektrostantsii na baze gazovyih turbin moschnostyu 16 MVt. Gas turbine power plants based on gas turbines with output capacity 16 MW.* Saint- Petersburg: REPH 2015. Available at: http://www.reph.ru/production/energetic

[11] Ministry of Energy of the Russian Federation. Available at: http://minenergo.gov.ru

[12] International Energy Agency. *Key world energy statistics*. Paris: IEA 2016.

Available at: http://www.iea.org/statistics

[13] PHILLIPOV A. *Poputnyj neftyanoj gaz nuzhen Rossii. Russia needs associated gas*. Moscow: Neftegas.RU 2013.

Available at: http://energas.ru/files/smi/maketi/13.06_png-1.pdf

[14] KUTEPOVA E., A. KNIZHNIKOV. *Problemy i perspektivy ispolzovaniya poputnogo neftyanogo gaza v Rossii. Problems and prospects of utilization of associated petroleum gas in Russia*. Moscow: WWF 2012.Available at: http://www.kpmg.com/ru/ru/issuesandinsights/articlespublications/documents/wwf_4_rus.pdf

[15] MORENOV V. *Povyshenie ehffektivnosti ehnergosnabzheniya obektov neftegazopromyslov s ispolzovaniem-poputnogo neftyanogo gaza v kachestve ehnergonositelya. Improvement of energy efficiency of oil and gas facilities using associated petroleum gas as an energy source.* Doctoral thesis. Saint- Petersburg: SPMI 2016.

[16] KABYSHEV A., S. OBUKHOV. *Raschet i proektirovanie sistem elektrosnabzhenija: spravochnye materialy po elektrooborudovaniju. Calculation and design of power supply systems: reference materials on electric equipment.* Tomsk: TPU, 2005. Available at: http://www.c-o-k.ru/images/library/cok/355/35545.pdf

[17] SEMENOV V. *Energeticheskiye gazoturbinnyye ustanovki i energeticheskiye ustanovki na baze gazoporshnevykh i dizel'nykh dvukhtoplivnykh dvigateley. Gas-turbine power plants and power plants based on gas piston and diesel dual-fuel engines*. Moscow: TECH 2014.

[18] TROFIMOV U. *Normativy zatrat na remont v protsentakh ot balansovoy stoimosti konkretnykh vidov osnovnykh sredstv elektrostantsiy. Normative costs for repair in percentages from the certain values of concrete types of power stations basic equipment*. Moscow: UES 2004.

[19] HOLDING MRSK. *Sbornik ukrupnennykh pokazateley stoimosti stroitel'stva (rekonstruktsii) podstantsiy i liniy elektroperedachi dlya nuzhd OAO «Kholding MRSK». Collection of enlarged indicators of the cost of substations and*

transmission lines construction (reconstruction) for the needs of OAO "Holding MRSK". Moscow: MRSK 2012.

[20] HOLDING MRSK. *Yedinyye tarify na uslugi po peredache elektroenergii na 2016 god. Unified tariffs for electricity transmission services for 2016*. Moscow: MRSK 2016.

[21] HOLDING MRSK. *Tarifnoye menyu po tekhnicheskomu podklyucheniyu. Technical connection tariff menu*. Moscow: MRSK 2016.

[22] BREALEY R. *Fundamentals of corporate finance*. New York: McGraw-Hill/Irwin, 2012.

[23] MILAEV V. *Metodika rascheta vybrosov vrednykh veshchestv v atmosferu pri szhiganii poputnogo neftyanogo gaza na fakel'nykh ustanovkakh. Methodology for calculating emissions of harmful substances polluting the atmosphere by associated petroleum gas flaring at flare facilities.* Saint- Petersburg: SPB 1998.

[24] Government of the Russian Federation. *Postanovleniye ot 13.09.2016 g. n 913 o stavkakh platy za negativnoye vozdeystviye na okruzhayushchuyu sredu i dopolnitel'nykh koeffitsiyentakh. Regulation of 13.09.2016 n 913 about payments rates for negative impacts on the environment and additional coefficients.* Moscow, 2016.

[25] KNIZHNIKOV A. *Problemy i perspektivy ispolzovanija neftjanogo poputnogo gaza v Rossii. Problems and prospects of using associated petroleum gas in Russia*. Moscow, WWF 2009.

[26] Federal state statistics service of Russian Federation. Available at: http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/en/main

[27] Trading Economics statistics service. Available at: http://www.tradingeconomics.com/russia/inflation-cpi

[28] Russian bonds. Available at: http://www.rusbonds.ru/cmngos.asp

[29] Federal tax service of Russia. Available at: https://www.nalog.ru/rn40/taxation/taxes

[30] Central Bank of the Russian Federation. Available at: http://www.cbr.ru/statistics

[31] PJSC GAZPROM. *IFRS consolidated interim condensed financial information*. Moscow 2016.

Available at: http://www.gazprom.com/f/posts/44/307258/gazprom-ifrs-3q2016-en.pdf

Appendices

Appendix 1. Fuel consumption calculation table

T, h	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Load, %	78,6	76,4	80,5	79,7	78,9	80,5	76,4	81,2	85,6	80,4	80,9	72,2	77,0	80,4
Fuel consumption, %	83,35	82,14	84,38	83,93	83,49	85,39	82,14	85,91	89,19	85,29	85,69	79,87	82,46	85,29
Total Fuel consumption, Kg/s	1,10	1,08	1,11	1,11	1,10	1,13	1,08	1,13	1,18	1,13	1,13	1,05	1,09	1,13
Total Fuel consumption, Kg	3961	3904	4010	3989	3968	4058	3904	4083	4239	4054	4072	3796	3919	4054
Total Fuel consumption, ths. m3	5,08	5,00	5,14	5,11	5,09	5,20	5,00	5,23	5,43	5,20	5,22	4,87	5,02	5,20
Fuel cost, RUB	1270	1251	1285	1279	1272	1301	1251	1309	1359	1299	1305	1217	1256	1299

Appendix 1. Fuel consumption calculation table (continuation)

T, h	15	16	17	18	19	20	21	22	23	24		
Load, %	82,3	84,2	81,4	81,4	81,6	85,3	87,2	87,2	74,5	68,1		
Fuel consumption, %	86,72	88,15	86,02	86,02	86,18	89,01	90,43	90,43	81,13	77,67		
Total Fuel consumption, Kg/s	1,14	1,16	1,14	1,14	1,14	1,18	1,19	1,19	1,07	1,03		
Total Fuel consumption, Kg	4121	4189	4088	4088	4096	4230	4298	4298	3856	3691		
Total Fuel consumption, ths. m3	5,28	5,37	5,24	5,24	5,25	5,42	5,51	5,51	4,94	4,73	$\sum_1^{24}$ =124,32	$\sum_{year}$= =45375,22
Fuel cost, RUB	1321	1343	1310	1310	1313	1356	1377	1377	1236	1183	**31 079**	**11 343 804**
											Fuel cost (day), RUB	**Fuel cost (annual), RUB**