УНИВЕРСИТЕТ ИТМО

Optimization of compressor station design and workload according to the energy efficiency criterion

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1.1 Gas industry resources costs

The gas industry, which includes such segments as exploration, production, transportation, processing and distribution of natural gas, is a large production complex and requires a significant amount of fuel and energy resources for its operation.

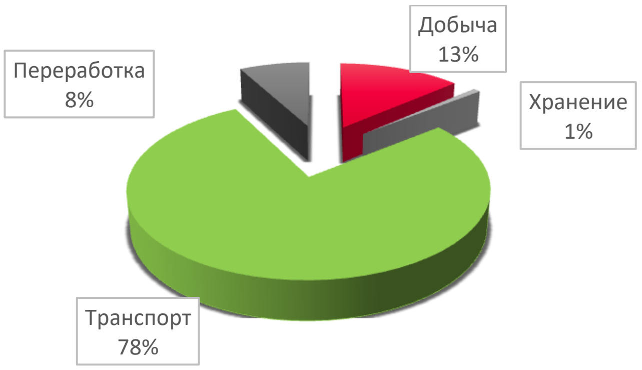
Consumption of fuel and energy resources by gas industry segments for 2016 [1].

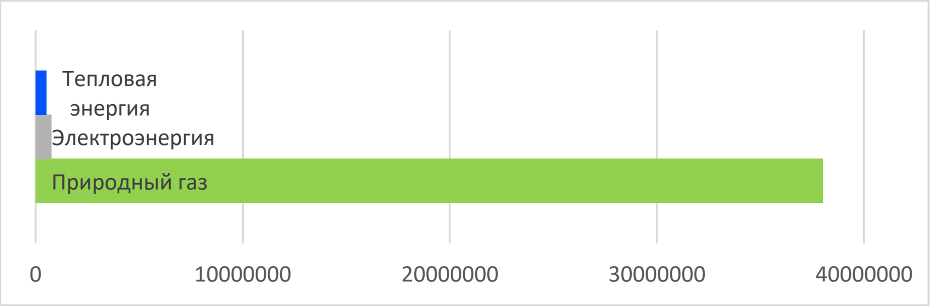
Industry segment	Natural gas, thousand m^3	Electricity, thousand kW / h	Thermal energy, Gcal
Production	5425853	1117127	2279660
Transportation	32489457	6255191	3684808
Storage	316078	91051	224600
Refining	1218529	11492	14895628

1.2 Resources costs for gas transport

The most energy-intensive segment of the gas industry is gas transportation, with fuel gas accounting for the most costs.

In this regard, the problem of reducing energy costs should primarily be aimed at improving the efficiency of compressor stations as the main consumers of fuel and energy resources.





1.2 Life cycle

In accordance with [ISO 15663-1], the life cycle is defined as, all stages of the development of an object of equipment or function, starting from the beginning of the study and ending with disposal.

Life cycle cost according to [ISO 15663-1] is the discounted aggregate amount of all costs incurred by a particular function or piece of equipment during its life cycle.

The life cycle in accordance with [ISO 15663-3] contains 6 main sequential stages:

- The choice of the project concept (development of the technical specification and technical requirements);
- preliminary design;
- technical design;
- production, tincture;
- usage, production, service;
- decommissioning.

1.3 Problem statement

Aim:

- Determine the implementation option of the CS that provides the highest criterion of energy efficiency - the installed capacity utilization factor (ICUF)

$$K_{ICUF} = \frac{n_{\text{р}}}{n_{\text{у}}} \cdot \text{К}_{av}$$

Under constraints :

- Project cost;
- The specified performance rate;
- Ensuring the specified level of reliability.

$$\begin{cases} \max\left(K_{ICUF}\right) \\ \sum_{i=1}^{m}(C_i) < C_{req}, \\ \sum_{i=1}^{m}(PR_i) > PR_{req} \\ \prod K_{Ai} > K_{A\_req} \end{cases}$$

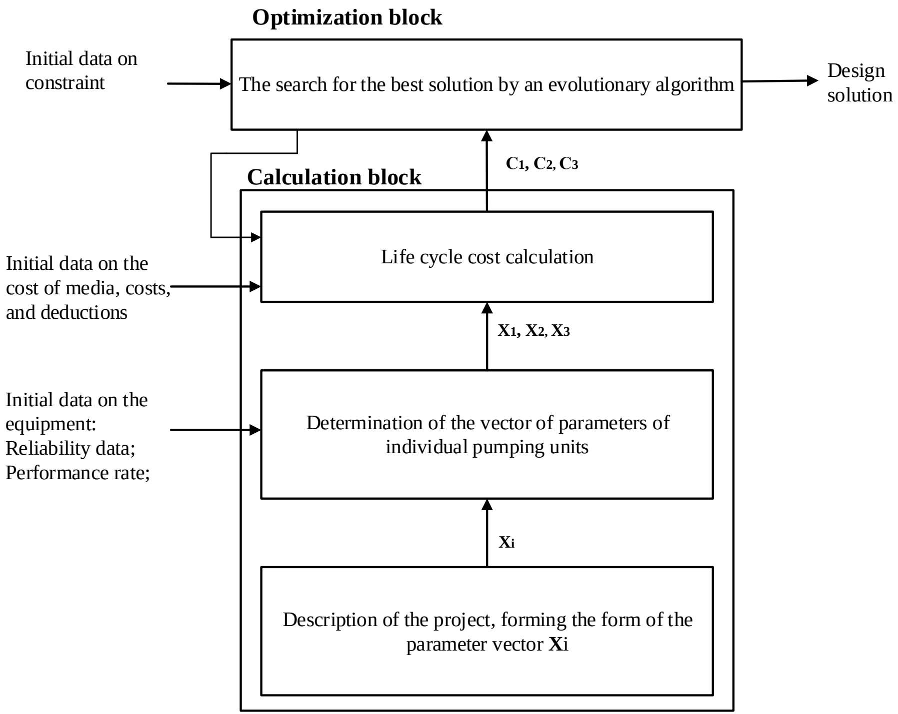
2.1 Description of the general approach

- **Calculation block**

Provides calculation of life cycle parameters depending on the number of units, operating mode and reliability of individual equipment units

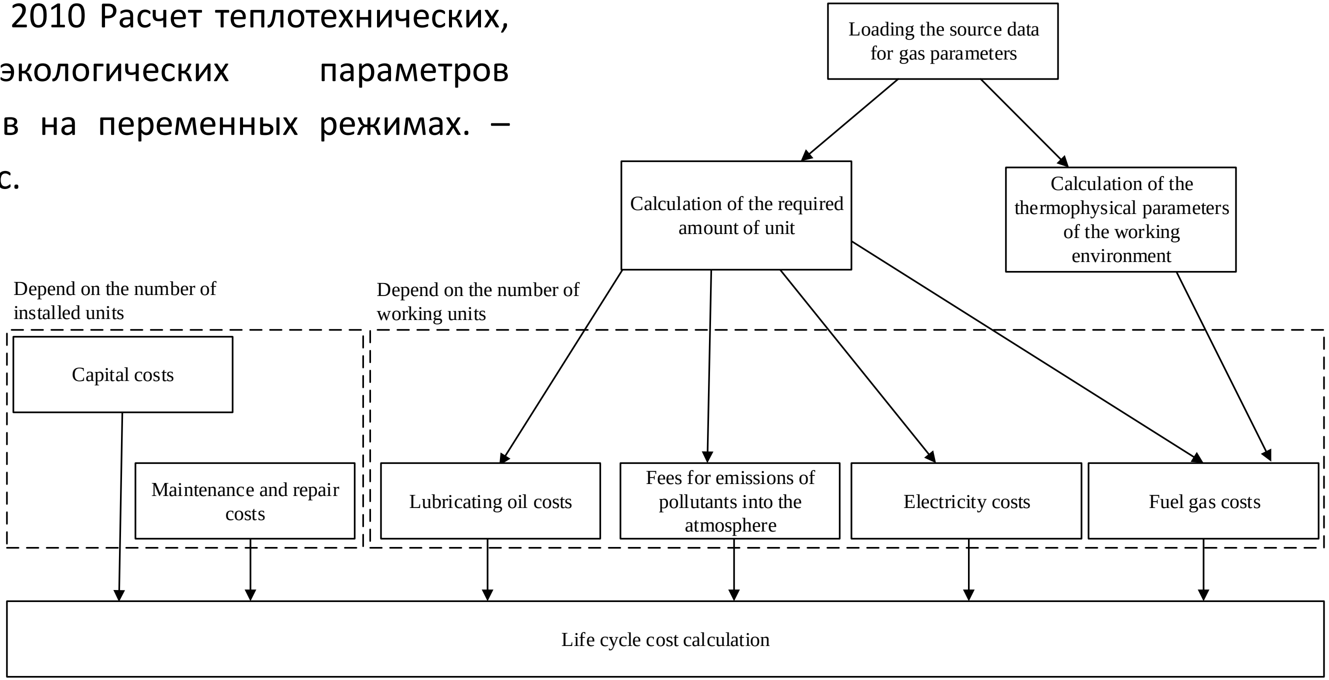
- **Optimization block**

Provides the generation of design decisions samples, forms the variability of decisions



2.2 Calculation block. Compression station model

- Р Газпром 2-3.5-438-2010 - 2010 Расчет теплотехнических, газодинамических и экологических параметров газоперекачивающих агрегатов на переменных режимах. – М.: ОАО «Газпром», 2010. – 70 с.
- Газоперекачивающие агрегаты с газотурбинным приводом на магистральных газопроводах: Учебное пособие для вузов / Б.П. Поршаков, А.С. Лопатин, С.М. Купцов, К.Х. Шотиди – М.: ООО «Издательский дом Недра», 2010. – 245 с.



2.2 Calculation block. Reliability assessment

Features:

- The probability of failure of safety measures can be determined by $q(t) = e^{-\lambda t}$, where λ is the equipment failure rate;
- Mean time to failure of an unit, in the case of an inconsistent connection in terms of reliability: $T_{MTTF} = \int_0^\infty P_i(t)dt$;
- Mean time to repair $T_{MTR} = \frac{\sum_{j=1}^{n} \lambda_j \cdot Z_j \cdot T_{3j}}{\sum_{j=1}^{N} \lambda_j \cdot Z_j}$, where T_{3j} replacement element recovery time
- Stationary value of the availability factor, $K_{Ai} = \frac{T_{MTTFi}}{T_{MTTFi} + T_{MTRi}}$

2.3 Optimization block

Features:

- An evolutionary algorithm is used as an approach to solving the optimization problem;
- Sample size per cycle – 100;
- Elite sample – 10;
- The initial vector of parameters is assumed to be equally probable;
- All parameters of the decision vector are assumed to be equivalent, random variables;

$$\widehat{\boldsymbol{v}}_{t,j} = \frac{\sum_{k=1}^{N} \mathrm{I}_{\{\hat{S}(\mathrm{X_k}) \geq \widehat{\gamma}_t\}} \mathrm{X}_{k,j}}{\sum_{k=1}^{N} \mathrm{I}_{\{\hat{S}(\mathrm{X_k}) \geq \widehat{\gamma}_t\}}}, j = 1, \ldots, n$$

- As a stop criterion, it is accepted $d_t = \max_{1 \leq j \leq n} \left\{ \min\{\widehat{\boldsymbol{v}}_{t,j}, 1 - \widehat{\boldsymbol{v}}_{t,j}\} \right\} \leq 0.01.$

2.4 The choice of software

Advantages of the R language:

- R-programming language for statistical data processing and working with graphics.
- free and open source computing environment under the GNU project;
- The R language contains tools that allow you to create several parallel threads of calculations (by simultaneously loading several processor cores) and reduce the time spent on modeling several times.

Application features:

- Generating random numbers with a given distribution law - Built-in language tools;
- Graphical representation - The package igraph ;
- Parallelization - The Foreach Package.

4.1 Initial data

Requirement:

- Performance rate – 50 MW;
- Availability factor – 0.99 per year;

Implementation options:

- Standard sizes of gas pumping units : 16 MW; 25 MW; 32 MW;
- Each of the gas pumping units can operate in fixed modes 70%, 80%, 90%, 100%;
- Each of the gas pumping units can have several versions of the oil supply system {M1, M2}, power supply {E1, E2}, and control system equipment {U1.1, U1.2, U2.1, U2.2}.

For all units of equipment, the cost, cost of use, reliability and maintainability indicators are known.

4.2 Design vector

Gas pumping unit $\hat{v}_1$:

	Power			Performance rate				OIL		Elect		Control			
Probability	0,333	0,333	0,333	0,25	0,25	0,25	0,25	0,5	0,5	0,5	0,5	0,25	0,25	0,25	0,25
Code	PW16	PW25	PW32	PR70	PR80	PR90	PR100	M1	M2	E1	E2	C1.1	C1.2	C2.1	C2.2

Gas pumping station $\hat{v}_t$:

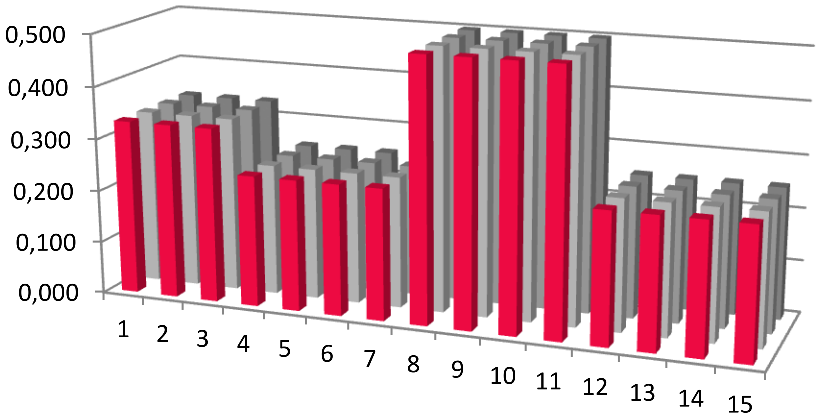
$$\hat{v}_t = \{\hat{v}_1, \hat{v}_2, \hat{v}_3, \hat{v}_4\}$$

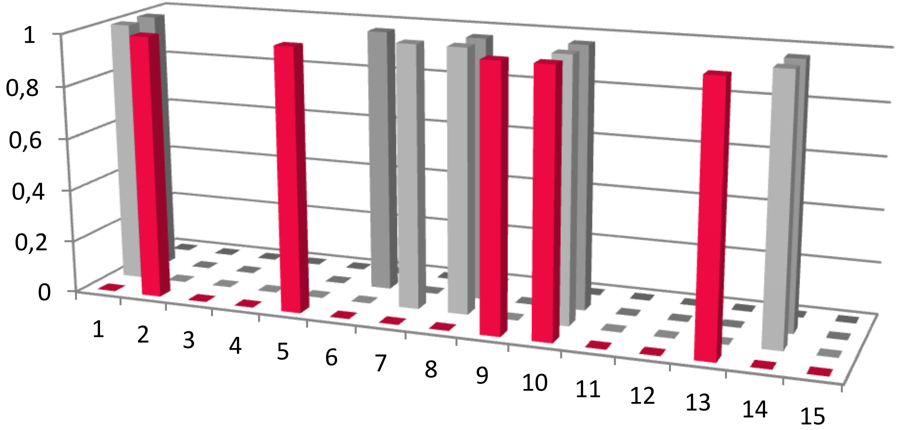
Each vector $\hat{v}_i$ contains 5 independent components, the total number of combinations for one vector is 192.

Total number of combinations for 4 gas pumping unit – 192^4 ~ 1,36E+9

5. Results

Vector dynamics $\hat{v}_t$





Vector $\hat{v}_t$ is solution

0	1	0	0	1	0	0	0	1	1	0	0	1	0	0
1	0	0	0	0	0	1	1	0	1	0	0	0	1	0
1	0	0	0	0	1	0	1	0	1	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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Conclusions

- A scheme for optimizing the design solutions of the Gas pumping station according to the efficiency criterion is proposed.
- A software implementation in the R language has been developed that provides calculation of the Gas pumping station life cycle parameters, reliability indicators for individual nodes and the station as a whole.
- Using the method of evolutionary search, a solution was found

Thanks for your attention!

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