The results of an estimation commercial effectiveness and competitiveness of the project of NPP with energy block BNGT-300 at a preproject stage

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Abstract. The parametric evaluation results for technical and economic indicators of the BNGT-300 nuclear power plant are shown.

In order to estimate commercial effectiveness and competitiveness, 4 sub-options were investigated, varying building expenses in the range of 2,400 to 9,500 $/kWe.

It is shown that the payback periods of considered 4 variants of capital expenses are have values in a range ~21÷23 year with discounting and ~12 years without discounting.

In the specified range of capital expenses the equivalent cost price has values in a range 2.59÷5.95 $cent/kWh (in Russian 1.23÷2.82 rbl./kWh), the equivalent selling price of zero profitableness - 5.57÷17.59 $cent/kWh (in Russian 2.64÷8.34 rbl./kWh), equivalent fair selling price - 6.57÷20.80 $cent/kWh (in Russian 3.12÷9.86 rbl./kWh).

The results of this estimation of commercial effectiveness and competitiveness present that the NPP with one energy block BNGT-300 can be competitive with 3 generating objects in territories of "no price zones" in all investigated range of capital expenses and with 6 generating objects in special territories of "price zones" if capital expenses do not exceed 3,400 $/kW of installed capacity.

With reference to the foreign market of power equipment the NPP with energy block BNGT-300 can be competitive to energy blocks of EPR on a building area of Hinckley Point if capital expenses for its construction do not exceed 6,600 $/kW of installed capacity.

Key Words: commercial effectiveness and competitiveness, payback period, capital expenses, equivalent cost price, equivalent fair selling price, equivalent selling price of zero profitableness.

1 Introduction

The implementation of estimations of technical and economic indicators (TEI in Russian – TEP) of the projects or projectible products at all design stages corresponds to requirements of government standards on: the technical proposal, the conceptual design and technical project. Results of such estimations can be recognized as new or innovative only because they concern new/innovative objects of technics or for the research of technical and economic indicators of offered samples of technics were used new tools.

The purpose of the present work within the limits of estimation TEI to define indicators of commercial effectiveness and competitiveness of the design, a construction and maintenance of one-block nuclear power plant (NPP) with energy block BNGT-300.

In the process of definition of the basic integrated indicators of efficiency of the project, performed in compliance with Methodical recommendations in efficiency estimation of investment projects [1], definition of competitiveness indicators of NPP as subject in the market of products of energetics is supposed, also:

- The equivalent cost price (CP) of the electric power, including definition of cost prices of separate products the NPP: the electric power, capacity and thermal energy if necessary [2];

- The equivalent fair selling price (FSP in Russian – SOT), including if necessary definition of selling prices of the same products [2].

FSP is inherent property of the project since it is defined on the basis of iterative calculations of the relational discounted payback period (RDPBP) of the project depending on the relational equivalent selling price (RESP) for the electric power and corresponds to a point in which the first derivative of function RDPBP=f(RESP) is equal «-1» [3], [4].

The application of the tool of FSP is illustrated by FIG. 1 on which axes X and Y have values: an axis X – RESP=ESP/ESPZP where ESP - the equivalent selling price for the electric power, and ESPZP - the equivalent selling price of zero profitableness for the electric power; axis Y – RDPBP=DPBPESP/DPBPESPZP where DPBPESP - the discounted payback period for current value of the equivalent selling price for the electric power, DPBPESPZP - the discounted payback period for the equivalent selling price of zero profitableness.

The FSP is assured positive profitableness of the project and the parity relations between manufacturer and acquirer of the products NPP, and also competitiveness the NPP of same or other capacity if FSP competing projects NPP will appear above. Therefore it is the most simple tool of comparison of competing energy block, including energy blocks of various capacities at all design stages.

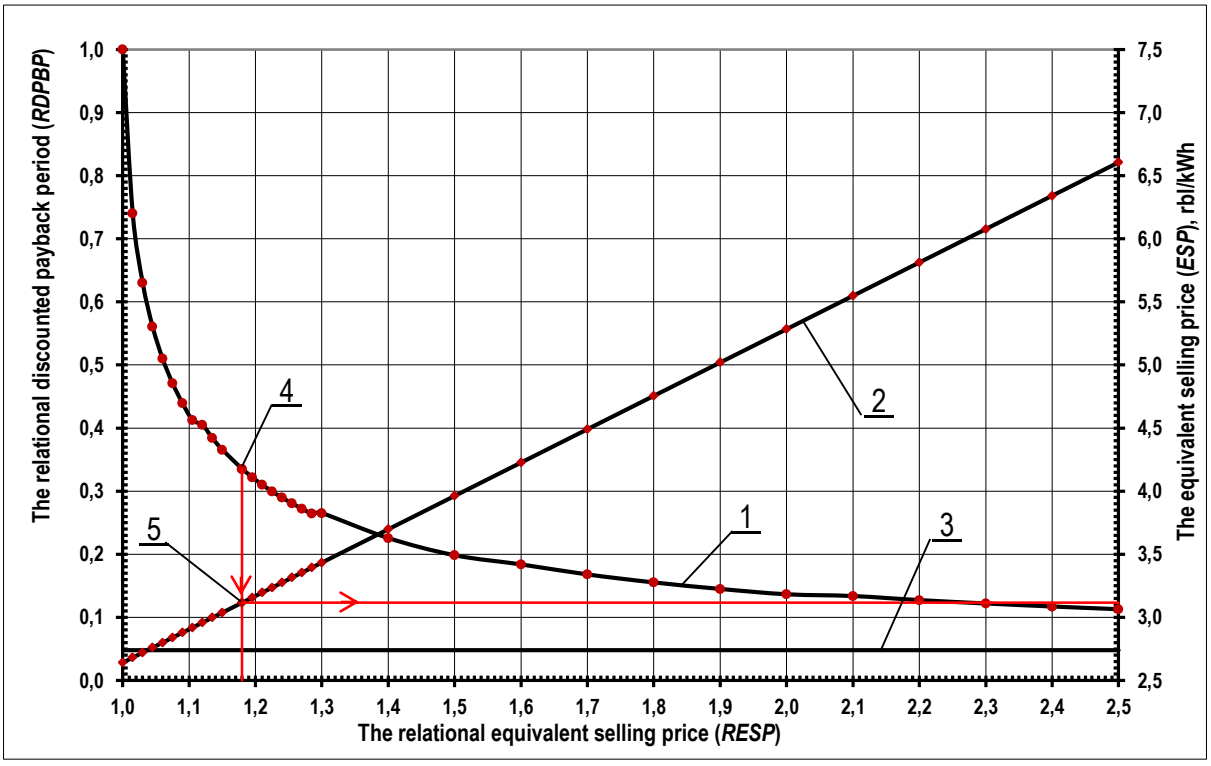

FIG. 1 Diagrams: 1 – RDPBP = f(RESP); 2 – ESP = f(RESP);
3 – limit of the schedule values RDPBP = f(RESP);
4 – point in which value of the first derivative function RDPBP = -1;
5 – value equivalent FSP = 6.58 $cent/kWh (in Russian – 3.12 rbl./kWh).

The role of reactors on fast neutrons in a sustainable development of nuclear energetics is well known. The application of sodium of fast reactor in a combination with gas-turbine energy-converter of the closed contour and a complex thermodynamic cycle (BNGT-300) will allow to pass to industrial manufacture of the main equipment (the reactor, the sodium - gas heat exchanger, the mentioned energy-converter) the NPP will provide delivery of blocks in full factory completeness to a construction place, including by rail with its dimensional restrictions.

2 Background/Problem Statement

The first mentions in media sources about energy block BNGT-300 dated back to 2004 [5] in "Russian Journal of Heavy Machinery" (in Russian - "Tyazheloe mashinostroenie") and at the International scientifical-practical conference «Small energetics» [6] and [7].

In 2005 at the International scientifical-practical conference «Small energetics» preliminary comparison of concepts modular the NPP of small and average capacity is presented, including the NPP with energy block BNGT-300 [8].

In 2006 the information about BNGT-300 is presented in the booklet of a branch innovative forum of Rosatom.

In 2007 energy block BNGT-300 description in IAEA format [9] is published.

In 2007 the further study of the project NPP with energy block BNGT-300 in cooperation of the organizations is executed: «SSC RF-IPPE» - the scientific adviser, «SPb Atomenergoproekt» - the general designer, «OKBM» - the chief designer of the energy block, «Salute» - the chief designer and the manufacturer of gas-turbine energy-converter. Results of study in part of circuitry decision are protected by the Eurasian patent [10]. The proposed configuration decision of BNGT-300: the sodium fast reactor in a combination with gas-turbine energy-converter of the closed contour and a complex thermodynamic cycle - provides the greatest electric capacity of the reactor block admissible to transportation by rail on the dimensional restrictions.

Possibilities of the energy block regarding maneuverability of capacity for tracing a network loading are protected by the patent [11]. The specified patent extends as well on energy blocks with heavy liquid-metal coolant and gas-turbine energy-converter with closed contour and a complex thermodynamic cycle, if the level of thermal stress of active zone provides low amplitudes of thermal rocking of fuel elements at maneuvers by capacity.

And finally in 2015 the draft proposal (DP in Russian – TZ) about scientific research and developmental work: «Engineering of the project of the nuclear energy-block with the sodium fast reactor and the energy-converter gas-turbine the capacity 300 MW(e) for the NPP of the fourth generation» was prepared. The material of the technical information on estimation of commercial effectiveness and competitiveness the NPP was prepared in addition to the draft proposal and is used in the present report.

3 Goals

As stated above, the research goals of TEI of the NPP with one energy block BNGT-300 to define commercial effectiveness indicators and competitiveness indicators of mentioned the NPP. The application of tool FSP for commercial effectiveness estimation by default provides positive values NPV and acceptable values of other basic integrated indicators of efficiency: IRR, PI, DPBP PBP. Therefore the main goal of research is definition of competitiveness indicators: the equivalent cost price of the electric power and FSP, which are defining in the course of iterative calculations of the relational discounted payback period in dependence on the relational equivalent selling price of the electric power.

Other research goal of TEI of the NPP with one energy block BNGT-300 is an estimation of influence on the listed indicators of competitiveness of the sizes of capital expenses, costs on the personnel, price of an active zone and other most significant articles of structure of the cost price, and also the discounting rate.

4 Details of the proposed research

The estimation of TEI for NPP with energy block BNGT-300 is made in constant costs since the look-ahead data on inflation on the period of 60 years project can’t be authentic.

If necessary, the estimation of an admissible inflation rate which at its invariable rates at the years the project will have positive profitableness, i.e. NPV≧0 can be executed according to a method presented in work [12].

The calculations are executed in the prices of Q4 2014. The average US dollar exchange rate for the stated period was 47.4243 rbl./$.

4.1 The energy block

The basic technical and economical characteristics the NPP with one energy block BNGT-300 presented in the table are accepted according to results of the tentative estimations included in mentioned above DP.

TABLE I The basic technical and economical characteristics NPP with BNGT-300

The thermal capacity, MW		840
The established electric capacity (gross), MW		304
The established electric capacity (nett), MW		300
The electric efficiency, %		36.2
The capacity for heating in 1CGM (nett):	MW	300
	Gkal/h	300
The load factor, %		95
The annual production	The electricity, GWh	2,529.9
	The heating, thousand Gkal	2,175.3
The part of capacity consumption for own needs, %		
	The electricity	1.3
	The heating	1.3
The annual selling to consumers:	The electricity, GWh	2,496.6
	The heating, thousand Gkal	2,146.7
The service life of the energy block, years		60
The service life of an active zone, years		5
The number of loadings by active zones		12
The selling volume for 60 years	The electricity, GWh	149,796.0
	The heating, thousand Gkal	128,801.4
The weight of ^{235}U in active zone, kg		3,350
The weight of the enriched UO_2 in active zone, kg		19,000
The average enrichment of nuclear fuel on ^{235}U, %		17.6

The estimation of a product market volume of the power equipment of such capacity can be executed on the basis of, for example, known European standard of consumption of energy 4 toe/capita/year that correspond to ~0.842 kW(e)/capita. For the specified norm of electric power consumption by only population the NPP with one energy block BNGT-300 will provide the necessities of ~356 thousand people or ~178 thousand people if half of capacity will be consumed by the manufacturing/business. In this range of town populace in Russia only 57 towns [13] (FIG. 2 see). The regions with such population is only 4 (FIG. 3 see). The most part of Russia towns (~69 %) has population from 10 to 100 thousand people. More than 100 thousand people - ~16 %, less than 10 thousand people - ~15 %.

NPP with BNGT-300 work only in a mode cogeneration (in Russian KGR). In 1st mode cogeneration (1KGR) selling of associated heating is made without decrease of the established electric capacity.

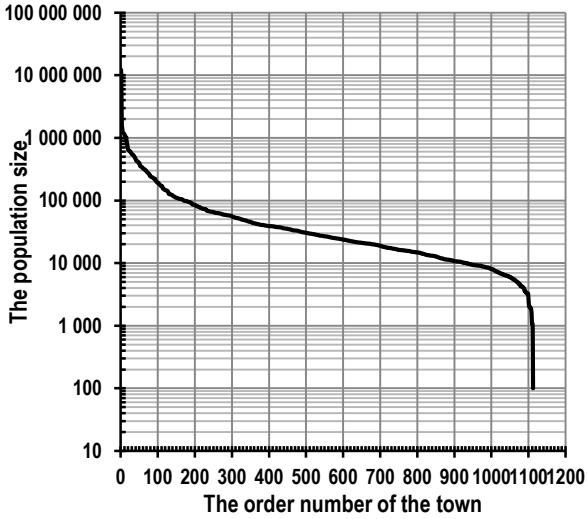

FIG. 2 The towns population

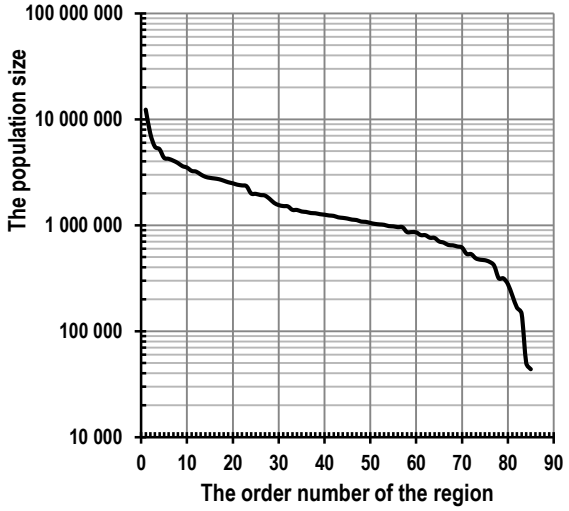

FIG. 3 The regions population

In 2nd mode cogeneration (2KGR) - with some decrease of the established electric capacity at the expense of decrease electric efficiency from 36.2 % to ~30 %. Thus in 2КГР useful use of thermal capacity of the nuclear power unit can reach ~92 %.

In 3rd mode cogeneration (3KGR) NPP is releasing to the consumer only high potential the heating (to 500°C) with the general thermal efficiency ~92 %.

Proceeding from the standard of consumption of heating, for example, for such cold region of Russia, as Republic Sakha (Yakutia) ~0.906 Gkal/capita [14], the real part of consumption of heating by the population in borders indicated above a range can be defined. It turns out that part of thermal energy of heating parameters, actually consumed by the population, will be ~15 % from assigned the NPP with energy block BNGT-300 in 1KGR. Therefore, contrary to opinion of some authors, and for atomic energetics it is important to have high efficiency, to reduce a thermal contamination of environment.

As the cold season on the European part of Russia usually lasts from 5 till 7 months, NPP with energy block BNGT-300 will work in the combined mode, selling in summer months, mostly, only the electric power, and in a cold season selling both the electric power, and thermal energy of heating parameters.

With reference to the present estimations of efficiency of the project the NPP with energy block BNGT-300 it is considered the sale only the associated heating in 1KGR, i.e. without decrease of the established electric capacity. The part of thermal energy of heating parameters in a cold season will be ~50 % from total volume of the energy for sale to consumers.

In summer months the sale of thermal energy if it is possible, only in the limited volume, therefore in efficiency estimations it is conditionally accepted that associated heating 1KGR is dumped on cooling stack. It is supposed that the cold season lasts 7 months (from October till April), therefore in 1KGR the NPP will be to work within 5,088 hours, and remainder 3,672 hours it will be to work in a selling mode only the electric power.

4.2 The results of an effectiveness estimation and competitiveness

The restrictions on volume of a represented material in the present research require to abandon discussion and a choice of the initial data and to consider directly the results of research, and in the limited volume at that. Therefore only results of research of influence of capital expenses for competitiveness indicators are presented in the present research.

For the project the NPP with one energy block BNGT-300 the estimation of commercial effectiveness and competitiveness is executed for 4 variants of the capital expenses in a range 2,400÷9,500 $/kW of installed capacity. At that cost of an active zone, annual expenses on the personnel, including insurance charges, indicators of an economic environment, the discounting rate 8 % of annual, expenses on a labor safety, expenses on a treatment of the spent fuel remain invariable for all variants of the capital expenses.

The growth of capital expenses is involving growth of such articles of the cost price, as: depreciation reserves, expenses on repair and maintenance service, on services of the subcontractors, and also all of other expenses in view of specificity of their calculations. The growth of assignments in reserves on safety ensuring depend from growth of equivalent FSP which grows in process of growth of capital expenses, providing positive indicators of efficiency for the variants of project.

The results of an estimation of indicators of competitiveness: equivalent FSP, SPZP, ECP for 4 variants of the capital costs are presented on FIG. 4.

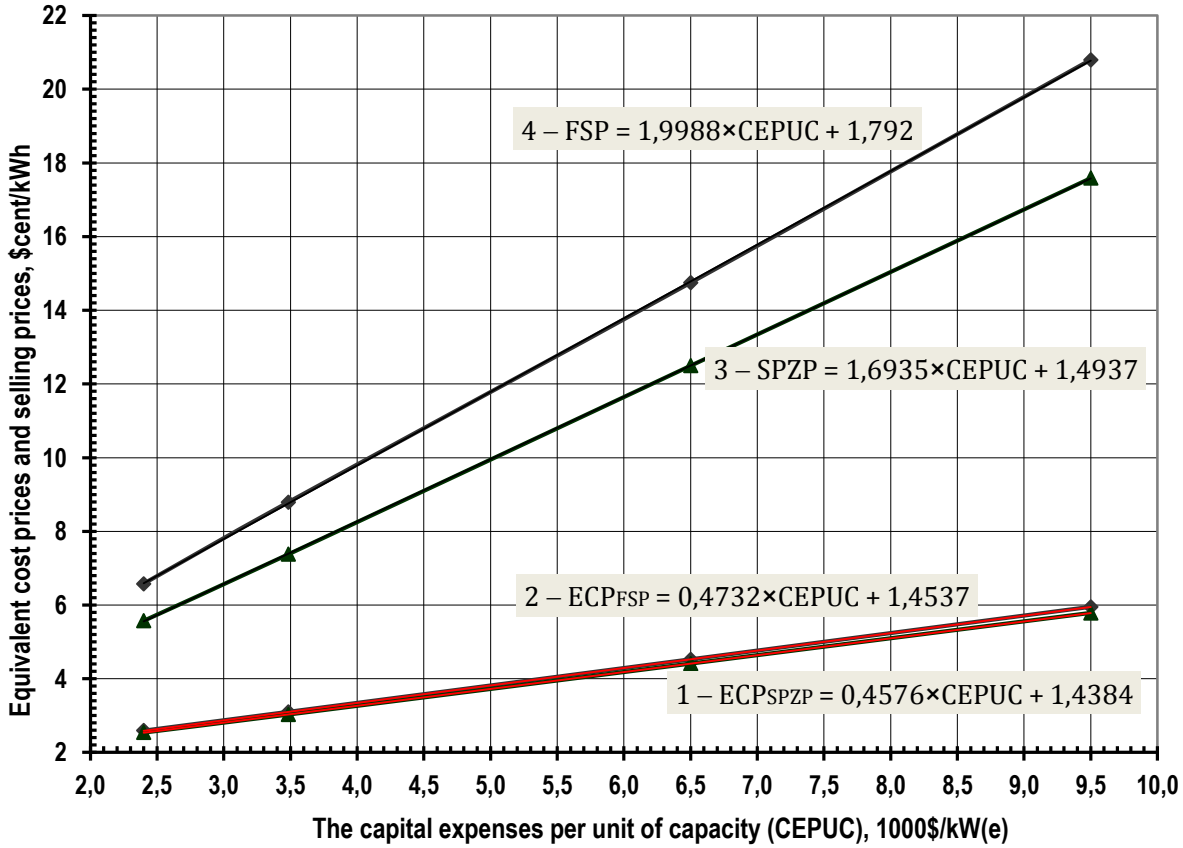

FIG. 4 The dependence of equivalent cost prices and selling prices from capital expenses per unit of capacity:
1 – Equivalent Cost Price for the Selling Price of Zero Profitableness;
2 – Equivalent Cost Price for the Fair Selling Price;
3 – Equivalent Selling Price of Zero Profitableness;
4 - Equivalent Fair Selling Price.

All indicators presented on a FIG. 4 have linear dependence on capital expenses per unit. Formulas for definition of their values in a range of capital expenses per unit 2,400÷9,500 $/kW are presented on a FIG. 4.

The payback periods of considered 4 variants of capital expenses are have values in a range ~21÷23 year with discounting and ~12 years without discounting.

In the specified range of capital expenses the equivalent cost price has values in a range 2.59÷5.95 $cent/kWh (in Russian 1.23÷2.82 rbl./kWh), the equivalent selling price of zero profitableness - 5.57÷17.59 $cent/kWh (in Russian 2.64÷8.34 rbl./kWh), equivalent fair selling price - 6.57÷20.80 $cent/kWh (in Russian 3.12÷9.86 rbl./kWh).

As it is known, in the Russian wholesale market of the electric power and capacity (in Russian OREM) it is accepted to allocate "price zones" and "no price zones" [15]. There are two "price zones", on a card (FIG. 5) they are noted by numerals 1 and 2.

The first "price zone" is territory of the European part of Russia and Ural Mountains. The second "price zone" is Siberia. Territories noted by numerals 3, 4 and 5 are related to the "no price zones".

"Price zones" there are territories for which features of functioning of the wholesale and retail markets are established. In these territories and in "no price zones" adjustable tariffs are applied.

FIG. 5 The zones of the wholesale market of the electric power and capacity in territory of the Russian Federation

The values of the equivalent selling price of the generating objects established by Federal antimonopoly service of the Russian Federation for 2016 in separate parts of "price zones" are shown on the FIG. 6 [16].

The values of equivalent selling price of the generating objects established by Antimonopoly service of the Russian Federation for 2016 for "no price zones" are shown on the FIG. 7 [17].

The presented schedules allow to notice that 9 generating objects as in separate parts of "price zones", and in "no price zones" deliver the electric power at equivalent selling price from 3 to 11 rbl./kWh while the NPP with energy block BNGT-300 could deliver electric power at equivalent FSP 3.12÷9.86 rbl./kWh in all investigated range of capital expenses from 2,400 to 9,500 $/kW of installed capacity.

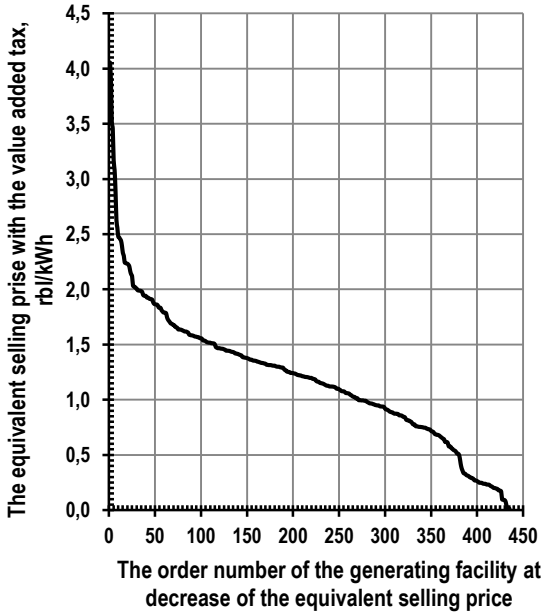

FIG. 6 For "price zones"

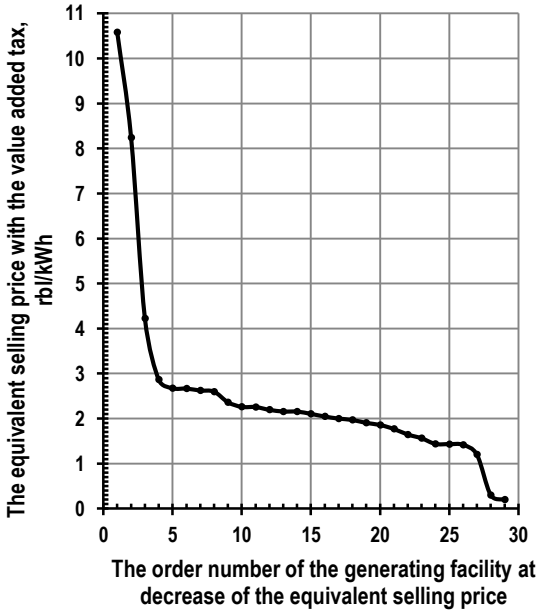

FIG. 7 For "no price zones"

All over the world the energy branch has the big social value and therefore in many cases it is subsidized by the governments.

As example, Great Britain government has entered into 10/21/2013 the agreement with company EDF on building of two blocks with reactors EPR on a building area of Hinckley the Point can serve.

Within the limits of this agreement the government of Great Britain guarantees the repayment of the electric power from blocks within 35 years at the price to 92,5 £/MWh (150 $/MWh or 15 $cent/kWh), «that more than twice exceeds current tariffs» [18].

The structure of the equivalent cost price for the NPP with one energy block BNGT-300 for extreme values of capital expenses per unit has a form as presented on the fig 8:

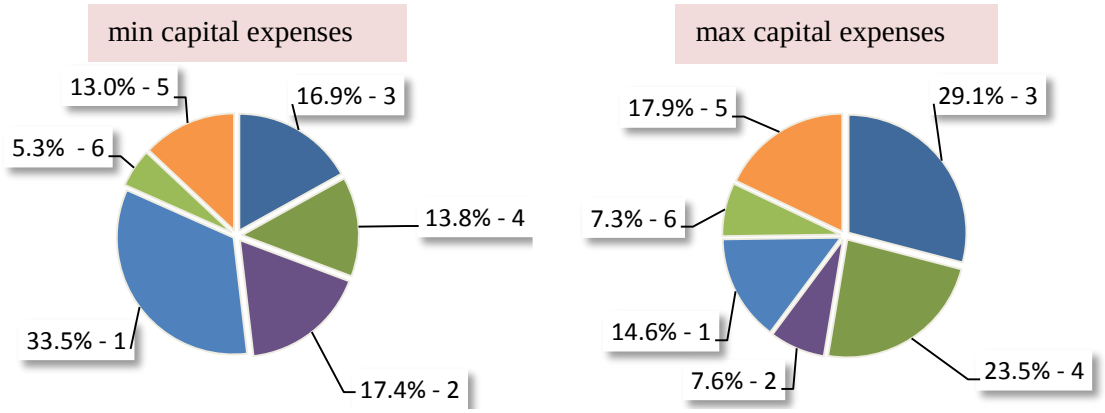

FIG. 8 1 – fuel; 2 – personnel; 3 - amortization expenses; 4 – maintenance; 5 – taxes&reserve allocations; 6 – sundry expense.

At invariable absolute values of expenses on the fuel and personnel the growth of capital expenses increases amortization expenses (sector 3). The expenses on repair and maintenance service (sector 4). The sundry expense (sector 6) increases owing to specificity of their estimation to proportionally the capital expenses. The taxes and reserve allocations (sector 5) grow basically at the expense of reserve allocations since they are defined proportionally to a receipts or equivalent FSP the growth which with growth of capital expenses provides positive profitableness and competitiveness.

5 Conclusions

The circuitry decision of energy block BNGT-300 consisting in association of fast sodium reactor with gas-turbine energy converter of the closed contour with a complex thermodynamic cycle has following advantages:

– in the conditions of restriction of dimensions of equipment at transportation by rail the greatest electric capacity 300 MW is provided;

– absence of intermediate sodium contour reduces both dimensions of the equipment of the energy block, and its steel intensity and, hence, its cost;

– there are no capital expenses for technology of water preparation for 2 contours of the energy block;

– relatively low fuel rating of an active zone provides 5 years of its operation to a maximal fuel burn-out 10 % ^{235}U, and possibility of maneuver by capacity without efficiency decrease that is provided by application of the specified type of the energy converter.

The energy block BNGT-300 in a greater degree is fit for power engineering of the big capacity, for example, in composition of 4 blocks NPP. The decrease of electric capacity of the individual energy block, for example, to 50 MW in composition of 4 blocks NPP will allow to increase service life of an active zone till 20 years, to refuse its forced cooling in favor of natural circulation, to provide continuity of power supply and to expand a commodity market.

The results of this estimation of commercial effectiveness and competitiveness present that the NPP with one energy block BNGT-300 can be competitive with 3 generating objects in territories of “no price zones” in all investigated range of capital expenses and with 6 generating objects in special territories of “price zones” if capital expenses do not exceed 3,400 $/kW of installed capacity.

With reference to the foreign market of power equipment the NPP with energy block BNGT-300 can be competitive to energy blocks of EPR on a building area of Hinckley Point if capital expenses for its construction do not exceed 6,600 $/kW of installed capacity.

6 Research Plan

According to the authors, the energy block BNGT-300 is applicable in a greater degree to average or big capacities, than to small capacities. For obtainment experimental acknowledgement about capacity for work the configuration decision of the energy block should execute experiments on the non-nuclear stand «SSC RF-IPPE» with the subsequent performance of technical proposal of the one-block NPP of small capacity in a range from 10 to 50 MW(e).

References

[1] The official publication, the second edition. (2000). *The methodical recommendations at estimate an efficiency of investment projects.* Moscow: Economics.

[2] Budylov, E. G. (2012). Design procedure of cost prices and selling prices for products of power from positions of power balance. *Preprint ФЭИ-3218*. Obninsk, Kaluga region, Russia: Publisher "SSC RF-IPPE".

[3] Budylov, E. G., Osheyko, Y. V., & Trevgoda, M. M. (2005). To definition of the fair selling price. *Materials ISPC "Small energetics-2005"* (pp. 201-207). Moscow: The publisher "Public corporation "Small energetics".

[4] Budylov, E. G., Osheyko, Y. V., & Trevgoda, M. M. (2006). The fair selling price - the tool of comparison and ensuring of competitiveness of energy technologies. *Materials ISPC "Small energetics-2006"* (pp. 311-318). Moscow: The publisher "Public corporation "Small energetics".

[5] Budylov, E. G., Trevgoda, M. M., Trykov, E. L., Ousanov, V. I., Osheyko, Y. V., & Kozlova, T. S. (2004, December). About some conditions of commercialisation of projects of atomic energetics on an example APS FSGT-300/100. *The monthly "Russian Journal of Heavy Machinery" (in Russian "Tyazheloe mashinostroenie").*

[6] Budylov, E. G., Poplavsky, V. M., Osheyko, Y. V., Trevgoda, M. M., & Trykov, E. L. (2004). The block-transportable nuclear thermal power station with the fast sodium cooled reactor and the gas-turbine energy-converter the capacity 300 MW(e) and 100 MW for central heating. Features and competitive advantages. *The materials of ISPC "Small energetics-2004"* (pp. 156-158). Moscow: The publisher "Public corporation "Small energetics".

[7] Budylov, E. G., Osheyko, Y. V., & Trevgoda, M. M. (2004). About some conditions of commercialisation of projects of atomic energetics and economic feasibility of a construction of the NPP very much low capacity on an example of the project of the Nuclear heating-power station BNGT-300/100. *The materials of ISPC "Small energetics-2004"* (pp. 174-176). Moscow: The publisher "Public corporation "Small energetics".

[8] Budylov, E. G., Osheyko, Y. V., & Trevgoda, M. M. (2005). Preliminary comparison of concepts modular the NPP of small and average capacity. *Materials ISPC "Small energetics-2005"* (pp. 163-173). Moscow: The publisher "The public corporation "Small energetics".

[9] IPPE, RF. (2007). TRANSPORTABLE MODULAR SODIUM COOLED REACTOR WITH GAS-TURBINE GENERATOR (BN GT-300). *IAEA-TECDOC-1536 "Status of Small Reactor Designs Without On-Site Refuelling"*. (pp. 504-508) Vienna, Austria: The publisher "IAEA".

[10] Trevgoda, M. M., Budylov, E. G., Osheyko, Y. V., & at alias. (2007, November 28). *Patent No. 010962*. Russia.

[11] Trevgoda, M. M., Budylov, E. G., & Osheyko, Y. V. (2012, March 5). *Patent No. 2502143*. Russia.

[12] Budylov, E. G. (2009). The criterion of zero profitability at an estimation of efficiency of innovative projects. *The preprint FEI-3163*. Obninsk, Kaluga region, Russia: The publisher "SSC RF-IPPE".

[13] "My town". (n.d.). *The number of resident populace of towns and regions of Russia on 1/1/2016*. Retrieved 12 7, 2016, from Web-site The national encyclopaedia of towns and regions of Russia "My town": http://www.mojgorod.ru/cities/pop2016_3.html

[14] The government of Republic Sakha (Yakutia). Regulation from 13/10/2012 г. # 446 *About the approval of standards of consumption of public services*. Retrieved 12/8/2016, from Web-site Electronic fund a legal and normative technical documentation: http://docs.cntd.ru/document/460157984

[15] The energy consultant. (n.d.). *What is the wholesale market of the electric power and capacity*. Retrieved 12/9/2016, from The web-site "The energy consultant. The Internet a portal of consumers of the electric power": http://www.energo-consultant.ru/sovets/yuridicheskim_licam/voprosi_energosnabgeniya/Chto_takoe_optovii_rinok_elektroenergii

[16] Federal antimonopoly service of the RF. (2015, December 13). *The appendix to order FAS of Russia from 12/13/2015 # 1294/15*. Retrieved December 2016, from The web-site "Federal antimonopoly service of the Russian Federation": http://fas.gov.ru/documents/legislative-acts.html

[17] Federal antimonopoly service of the RF. (2015, November 27). *The appendix to order FAS of Russia from 11/27/2015 # 1177/15*. Retrieved December 2015, from The web-site "Federal antimonopoly service of the Russian Federation": http://fas.gov.ru/documents/legislative-acts.html

[18] AtomInfo.ru. (2013, November 22). *The transaction with EDF on building of the new block of the British nuclear power plant "Hinckley Point" is concluded*. Retrieved December 9, 2016, from The web-site "The Russian nuclear community": http://www.atomic-energy.ru/news/2013/10/22/44565