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COMPARATIVE ANALYSIS OF METHODICAL APPROACHES TO EVALUATING THE EFFICIENCY OF INVESTMENT PROJECTS IN THE POWER INDUSTRY

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INTRODUCTION

At present time, a transition is made to market mechanisms of economy functioning based on equilibrium price formation for products of enterprises and their self-financing. Based on long-term forecasts of economic development, electric power industry should not only ensure preservation of the accumulated potential but should also provide for modernization, reconstruction, service life extension of operating power facilities and construction of new ones. Under market conditions, nuclear power installations will have to prove their right to exist and develop in competition with other power technologies. In these conditions, the responsibility is growing for the correctness of investment decisions taken in the power industry and methods on which they are based.

This paper analyzes currently used calculation methods for economic efficiency of investment projects. It emphasizes the limitations and drawbacks of the existing methodical approaches, and their inconsistency with market economy and scientific and technological progress (STP). The said drawbacks lead to serious mistakes in evaluating the prospects for the development of nuclear power. The paper describes a methodical approach based on equilibrium price formation that does not have the said drawbacks and may be used as the basis for further work on creation of improved calculation methods for the economic efficiency of investment projects in nuclear power.

LEVELIZED PRODUCTION COST METHOD

At present time, a methodical approach based on comparison of levelized generating costs /1/ is used by IAEA and OECD to evaluate the efficiency of investment decisions. They recommend for implementation the project that has the minimal levelized product cost value C determined by the following equation:

$$\tilde{N} = \frac{\sum_{t=0}^{T}(K_t + U_t)(1+E)^{-t}}{\sum_{t=0}^{T} Q_t (1+E)^{-t}} \quad (1)$$

where t - is the current year of the project implementation, T - is the duration of the project's life time, K_t - are the capital investments in the year t, U_t - are the operation & maintenance cost (without amortization) in the year t (with regard for the fuel constituent), Q_t - is the power generation in the year t, E - is the discount rate.

Let's consider particular examples of using the comparison methods for levelized costs. Let's choose as installations for comparison a 2-unit NPP with a VVER-1000 reactor design number 392 (RD-392), a 2-unit NPP with a VVER-1000 reactor design number 428 (RD-428) and an co-generation power plant (CGPP) with 4 units of 450 MW each. The technical and economic characteristics of these installations are presented in Tab.1.

Table 1. Technical and economical characteristics of CGPP-450 and VVER-1000 design projects

		CGPP-450	RD-392	RD-428
1.	Number of power units	4	2	2
2.	Number of years of construction of power installation	7	10	10
3.	Years of completion of construction of power units	4,5,6,7	8, 10	8, 10
4.	Number of years of operation of power unit	30	40	40
5.	Specific capital investments, $/kW	750	920	1297
6.	Installed electric power of power unit, MW	450	1068	1060
7.	Auxiliary electric power, %	2	6.1	5.8
8.	Fuel price for SGPS, $/1000m^3 Fuel cost for NPP, cent/kWh	60	 0.7	 0.7
9.	Nuclear fuel burnup, MW*day/t	-	43000	43000
10.	Enrichment for U235, %		4.4	4.4
11.	Number of year of temporary operation of power unit	1	2	2
12.	Capacity factor during temporary operation period, %	0.6	0.35, 0.6	0.35, 0.6
13.	Capacity factor during normal operation period, %	0.8	0.8	0.8

A special role in analyzing the levelized cost is given to the discount rate selection. Due to a considerable capital intensity and a long period of the construction of power installations, and nuclear power units in particular, normally used variations of this indicator in the values range of the possible crediting interest rate for power installations (5-12%) may lead to directly opposite conclusions with respect to their economic efficiency. Besides, the necessity of levelizing the power generation (i.e. the selection of the denominator in eq.(1)) requires explanation which questions the correctness of the commonly accepted levelized cost determination.

The value C calculation results at different levelizing values are presented in Fig.1. The analysis of the presented dependencies allows to conclude that an NPP with a VVER-1000 (RD-428) is not competitive at the applicable technical and economic characteristics based on the minC criterion for the entire values E range used.

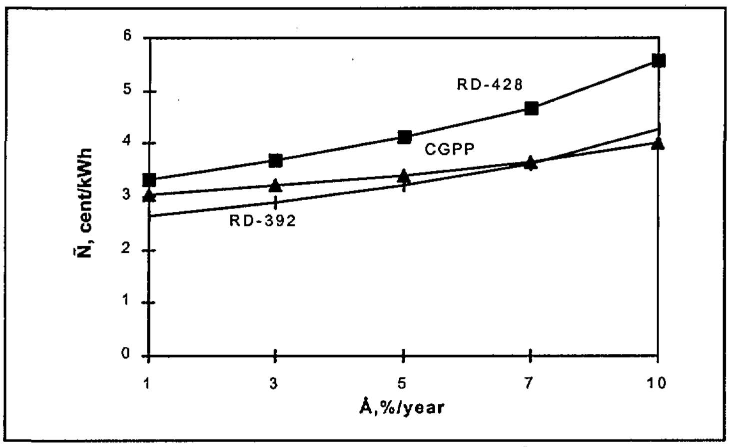

Fig.1. Dependency of value C on discount rate E for VVER-1000 (RD-392), VVER-1000(RD-428) and CGPP-450 design projects.

The NPP with VVER-1000 (RD-392) stops to be competitive for the discount rate values E of over 0.07 (7%/year). At the same time, the existing practice of using in calculations the discount rate value of E=10%/year is not accompanied with a strictly scientific explanation as to the selection of this value based on consideration of the economic content of the discount rate. It follows from /2/ that the discount rate E in eq.(1) can be determined the expenses responsible for the obsolescence of products and, espectively, E is the obsolescence rate, rate of STP. This is exactly what explains the necessity of levelizing in eq.(1) not only expenses but the results (i.e. generations of products) as well.

Besides, the minC criterion comparison result is the selection of the only power technology with a completely denied probability of competing technologies to be developed, which actually ignores of the existing structure of generating facilities in the power system, the infrastructure of the fuel cycle, leave alone the system influence of separate power technologies on the equilibrium price of electric power.

Hence, the analysis of evaluation methods for the economic efficiency of power installations (technologies) based on the minC criterion allows to identify the following provisions that require a more strict substantiation:

- it is necessary to specify the economic content and strictly substantiate (without referring to the will of banks) the selection of the discount rate value as, without it, it is impossible to give a firm answer to the question concerning the economic efficiency of power installations (technologies);
- the necessity of levelizing power generation for the entire life cycle of the project has not been strictly substantiated in economic terms;
- the influence of the proportions that have formed in branches of the fuel and energy economy and the return influence of the power installations selected for implementation on the price of electric power in the power system.

NET PRESENT VALUE (NPV) CRITERION METHOD

At present time, economic efficiency calculation methods based on using a max(NPV) criterion are used widely /3/. The positive value of NPV indicator is the basic ground for taking a single investment decision:

$$NPV = \sum_{t=0}^{T}(D_t - Z_t)(1+E)^{-t} \qquad (2)$$

where D_t - is the total project income (from the sale of electricity) in the current year t of its implementation, $Z_t = K_t + U_t$. - are the total expenses (see eq.(1)) in the year t.

For a comprehensive analysis of the project in terms of financing patterns, evaluation of liquidity and safety of the project for its participants, such indicators as the internal rate of return (IRR), the profitability index of investments (PI), the discount pay-back period (DPP) /3/ and others are used in addition to the NPV. And it is recommended that calculations should use price levels determined within the framework of the federal wholesale electric power and capacity market.

Let's use the data in Tab.1 as an initial information for a practical analysis of these methods. The NPV calculation results for the values range of E=1÷10%/year are presented in Fig.2. A change of the discount rate E values in this range leads to opposite conclusions on the competitiveness of the power technologies under comparison. The NPV amount determines the formed cash flow which makes the enterprise's profit.

However, when the NPV methods are used, no substantiated conclusions are made on the necessary amount and areas of application of this profit. Such uncertainty arises out of essentially rated approach to price formation for electric power. The price size has turned out to be in no way connected with the equilibrium price, does not take into account the self-financing conditions and the mutual influence of the evaluated installations (technologies) and the power system.

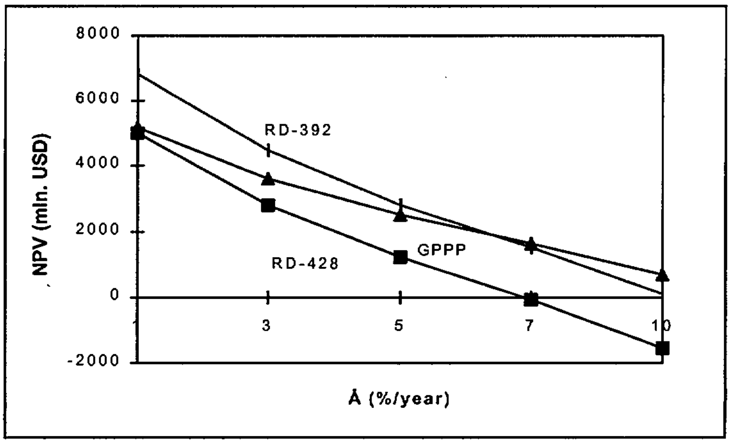

Fig.2. Dependency of NPV value on discount rate E for VVER-1000(RD-392), VVER-1000(RD-428) and CGPP-450 design projects.

In generalizing the conducted analysis, there should be identified the main drawbacks inherent in the calculation methods for the comparative economic efficiency of investment projects based on the max(NPV) criterion:

- the uncertainty in selecting the discount rate E is the same as in using the minC criterion which is necessary for the correct reduction in time and the comparison of the calculation results; the uncertainty is to a large extent connected with the absence of the indicator economic substantiation;
- the absence of a strictly substantiated position with respect to determining the tariff of electric power; the use of the actually rated approach to price formation excluding the objective market economic mechanisms of regulation and determination of the competitiveness;

- the absence of a substantiated approach to using the profit gained by power installations.

In comparing the analysis results for methodical approaches to evaluating the comparative economic efficiency of investment projects, it should be noted that the main cause leading to contradicting results of the evaluative calculations, is the absence of a system approach to analyzing different power technologies and a scientifically substantiated concept for performing the economic calculations.

EQUILIBRIUM PRICE FORMATION METHOD

The above contradictions in the existing methods of determining the efficiency of investment projects in electric power, considerably reduce the practical value of the evaluation results obtained using them and do not provide for the possibility of carrying out a strictly substantiated research of the nuclear power development prospects.

The drawbacks of the methodical approaches based on the minC and max(NPV) criteria may be to a large extent eliminated by applying an equilibrium price formation model /4, 5/ to the practice of taking design approaches and by considering the current financial activities of operating power installations under the conditions of market mechanisms being formed in Russian economy. Let's turn to determining the basic provisions of the equilibrium price formation model /2/, /5/.

Under the conditions of the equilibrium process of a power system functioning, the price for electric power will be formed under the influence of each of the producers. To determine the equilibrium price in this case, it is necessary to solve the following system of equations based on generalized determination of specific reduced expenses for generation of products by each of the producers and the equilibrium principle consisting in the equality of market prices for similar products (electricity) for all producers (power plants or technologies):

$$
\begin{aligned}
P_e &= C_1 + R_1 * Y_1 \\
Đ_e &= C_2 + R_2 * Y_2 \\
&- - - - - - - - \\
P_e &= C_i + R_i * Y_i \\
&- - - - - - - \\
P_e &= C_n + R_n * Y_n
\end{aligned}
\qquad (3)
$$

$$Y = w_1 * Y_1 + w_2 * Y_2 + \ldots + w_i * Y_i + \ldots + w_n * Y_n , \qquad (4)$$

where w_i - is the share for the i-th technology in meeting of the demand in the power system (power market), $\sum w_i = 1$.

The following designations have been introduced in the eq.(3): P_e - is the equilibrium (market) price of electric power common for all producers, /cent/kWh/; C_i - is the discount (i.e. with impact of STP) cost of the products of i-th producer, /c/kWh/; R_i - is the indicator of the specific expenses for the development of i-th producer, (cent*year/kWh); Y_i - is the individual development rate of i-th producer, (1/year) determining the change in the power generation in the current year (the calculation step).

The analysis of the eq.(3) and eq.(4) allows to conclude that the amount of the discount cost C_i cannot fully serve as the criterion for evaluating the economic efficiency of a power technology as compared with competing ones as it is only one of the factors that influence in the individual development rate and the equilibrium price.

Let's prove it by deriving an equation for the NPV in using the equilibrium price method. After simple conversions we get the following equation:

$$\text{NPV}=\frac{R_i Y_i Q_i}{E_r}. \tag{5}$$

where Q_i - is the power generation of i-th producer in the year t; E_r - is the reduction indicator ($E_r=E/(1-e^{-ET})$, T - is the duration of the project's life time). The analysis of the eq.(5) shows that the NPV value depends both on the individual development rate Y_i of the power technology and the selection of the reduction year. The profitability index /3/, calculated by using the eq. (5), looks as follows:

$$PI=\frac{R_i Y_i Q_i}{K_d}. \tag{6}$$

where $K_d=\sum K_t(1+E_c)^t$ - is the amount of the levelized (i.e. with the interest during construction E_c) capital investments. The profitability index also appears to be directly proportional to the value of the individual development rate Y_i. Then, after different conversions, we get the expression for the internal rate of return (*IRR*) calculation: $IRR=E+PI$.

The presented methodical approach to calculation of the comparative efficiency based on equilibrium price formation is economically substantiated in terms of market mechanisms (conditions of self-financing) and the system approach taking into account the multi-factor influence on the development of a particular power technology. The substantiation of the economic meaning and the discount rate value as the obsolescence rate, convinces that it is necessary to finance scientific developments allowing to provide for the competitiveness and development of each particular power technology. The equilibrium price is formed in accordance with the substantiated rates of the power system development (i.e. the growth in demand) and excludes the obtaining of unreasonable profit by unscrupulous producers. This approach does not repudiate less competitive technologies whose share of presence in the market depends on technical and economic characteristics and the growth rate of the demand for electric power.

The analysis of the discount cost's dependencies on the discount rate value E (Fig.1) shows that the currently used E values lead to underestimation of the competitiveness of nuclear power installations based on the minC and max(NPV) criteria. At values of E>8%/year, projects of NPPs with VVER-1000 cannot compete with CGPP (when used in evaluations of technical and economic characteristics and price guides often used nowadays). However, the use in economic evaluations of a substantiated discount (i.e. STP) rate value of E=1÷3%/year /2/ makes the VVER-1000 (RD-392) design project more attractive than CGPP and considerably reduces the electricity cost for the VVER-1000(RD-428) design project.

The comparative efficiency of technologies was evaluated based on equilibrium price formation for mathematical economic model of the power system functioning. The power system (power market) with a generation structure for thermal and nuclear power plants was taken as $w_{npp}=0.3$ (30%) for NPPs and $w_{CGPP}=0.7$ (70%) for CGPP. The individual development rates of power technologies was calculated for two models of power systems at variations of the power system development rate and discount rate indicator values. The analysis of the dependencies Yi=f(Y) (Figs.3 and 4) for the model of an NPP with VVER-1000(RD-392) shows that the individual rate Yi is positive for any combination of the E and Y parameters within the value range considered. So, a conclusion can be made on the development of each competitive power technology but with different individual rates Yi, and such that to ensure the meeting of the demand in the power system growing with the rate Y. (We remind that the methods described before fully exclude the development of installations that are not competitive). The growth of the system rate has a decisive influence on the ratio between individual development rates of the compared power installations (RD-392 and CGPP). Having a lower capital intensity and a shorter period of construction, CGPP are the prevailing power source in the conditions of a rapid increase in the power consumption (at Y=5÷10%/year), Figs.3 and 4). Nuclear power is more competitive in the conditions when the power consumption growth rate will be 1÷5%/year.

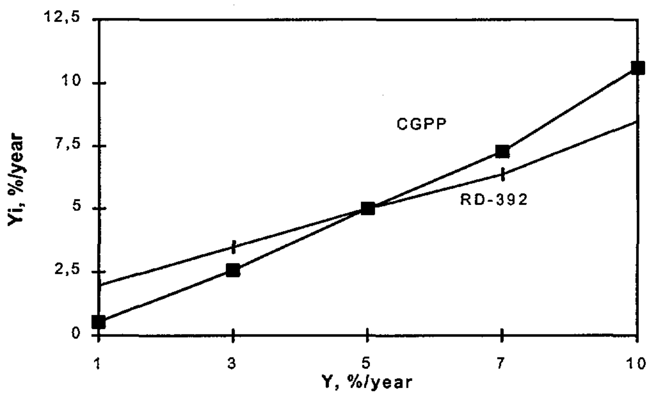

Fig.3. Dependency of technology development individual rate Yi on system rate Y (power system: VVER-1000(RD-392) and CGPP, E=1%/year).

Calculations for the second model using NPPs with VVER-1000 (RD-428) as nuclear power installations are presented in Figs. 5 and 6. At values of E=1%/year (Fig.5), Yi is always positive for both power technologies. At values of E≥3%/year, negative values of Yi for VVER-1000(RD-428) appear, i.e. this power technology will degrade at the rates of Y<1%/year (Fig.6) and will be substituted with more advanced and competitive projects. Each power technology has its own critical rate at the transition through which the respective technology transfers to the degradation state from the development state and vice versa.

The analysis of the dependencies in Fig.6 evidently shows again the influence of the growth in the demand for electric power Y on the competitiveness and promotion of the expenses for scientific and technological progress. An increase in the system rate Y leads to a growth of Yi for VVER-1000(RD-428) (Fig.6) as the competitive power technology having a specified set of technical and economic characteristics and price parameters cannot ensure so efficiently the respective increment of its generating capacities in this time interval. The development of the CGPP technology only will require a higher tariff than a simultaneous equilibrium development of NPPs and CGPP.

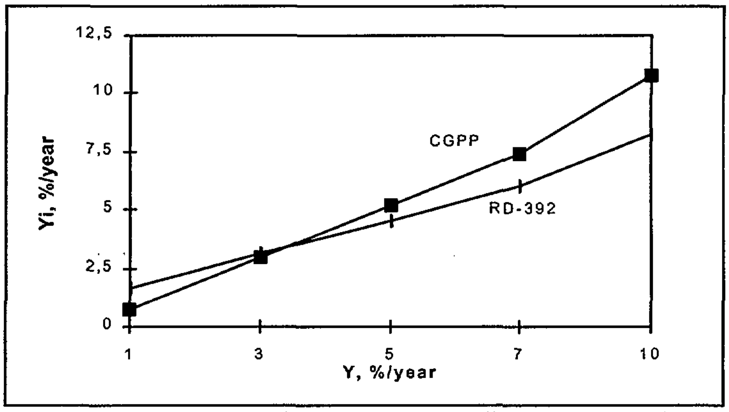

Fig.4. Dependency of technology development individual rate Yi on system rate Y (power system: VVER-1000(RD-392) and CGPP, E=3%/year).

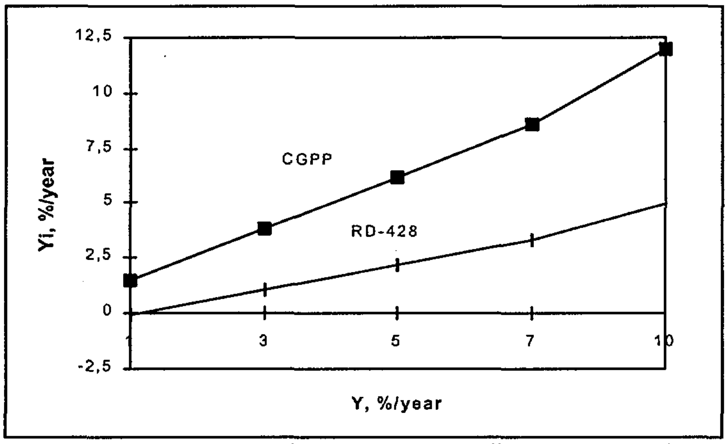

Fig. 5. Dependency of technology development individual rate Yi on system rate Y (power system: VVER-1000(RD-428) and CGPP, E=1%/year).

Equilibrium prices which are compared with discount costs for nuclear and thermal power were calculated for two models and specified levels of the power consumption growth Y (Figs. 7-10). To ensure the conditions of an economic operation of a power technology, its discount cost should be less than the equilibrium price that has formed in the power system. Otherwise, the required operating costs are covered first for account of spending depreciation charges and subsequently at the account of selling the enterprise's fixed assets when the individual power technology development rate is negative (Figs.7-10). Representative is the fact that the equilibrium price is fixed in the power system at the system rate of Y=0 at a level lower than the discount cost of the "worst" power technology.

Hence, the self-financing price should be obligatorily linked to a definite power system development rate Y. So, it is a serious methodological mistake to appoint prices without indicating to which rate they relate. In generalizing the results of the research into the methodological approach based on equilibrium price formation, we may propose the following stage-by-stage calculation pattern for the comparative economic efficiency of investment projects in nuclear power:

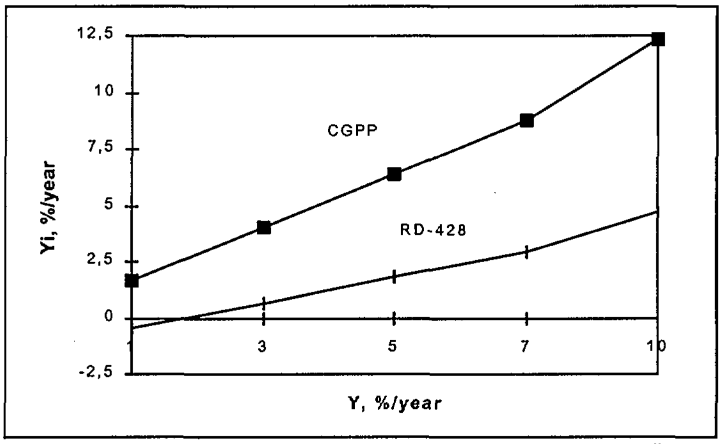

Fig.6. Dependency of technology development individual rate Yi on system rate Y (power system: VVER-1000(RD-428) and CGPP, E=3%/year).

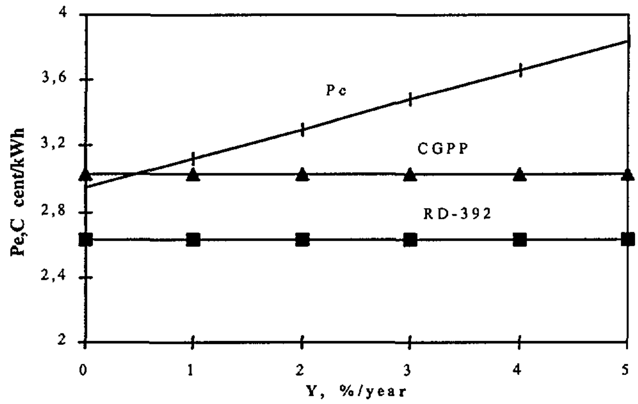

Fig.7. Dependency of the equilibrium price P_e and levelized costs C for VVER-1000(RD-392) and CGPP on system rate Y (E=1%/year).

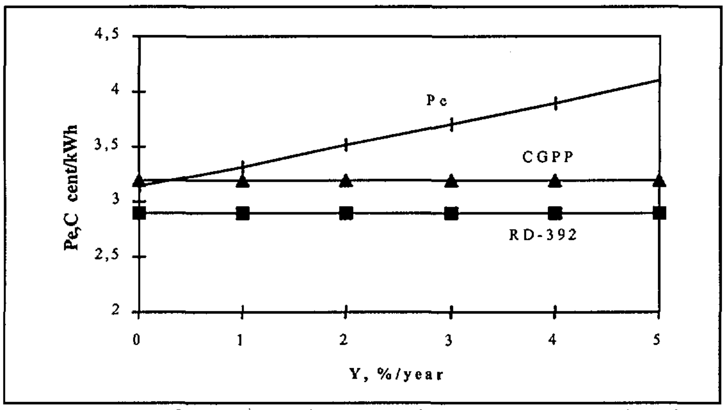

Fig.8. Dependency of the equilibrium price P_e and levelized costs C for VVER-1000(RD-392) and CGPP on system rate Y (E=3%/year).

- Power consumption growth rates are determined for each power systems based on the forecasts of the country's economy development;

- Types and projects of power plants are identified for meeting the specified share of the electric load schedule, and possible places for construction of power installations are planned;

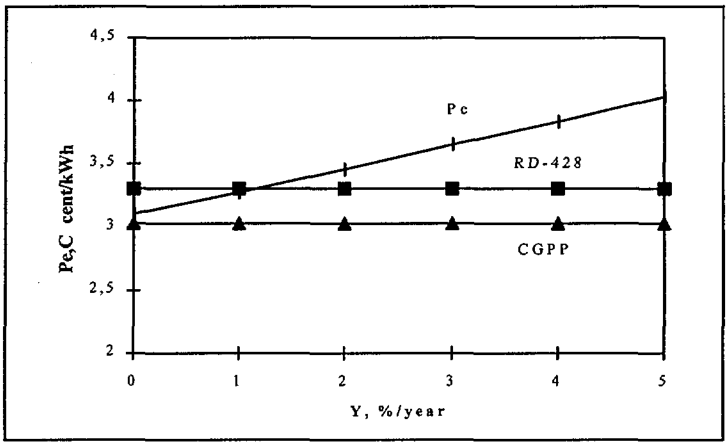

Fig.9. Dependency of the equilibrium price P_e and levelized costs C for VVER-1000(RD-428) and CGPP on system rate Y (E=1%/year).

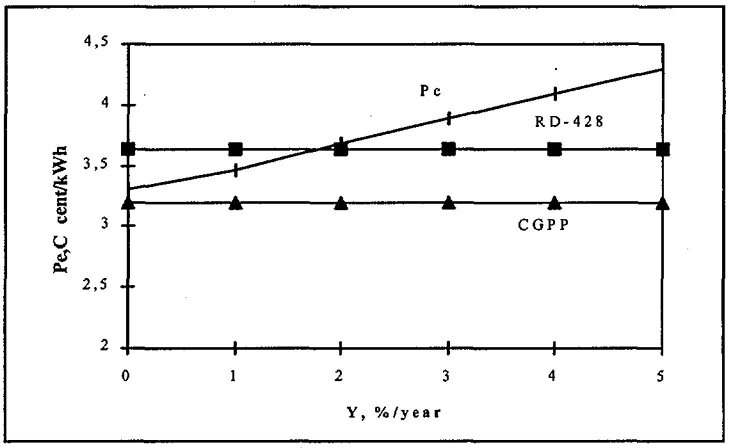

Fig.10. Dependency of the equilibrium price P_e and levelized costs C for VVER-1000(RD-428) and CGPP on system rate Y (E=3%/year).

- The construction program is formed, and the possible source and conditions of the project financing are planned;
- The power installation's production program is specified and all constituents of the production costs are shaped;
- Additional expenses for fuel supply and network construction are calculated for the selected location;
- The equilibrium price for the considered power system and individual development rates of the compared variants are determined;
- Parameters of the project's commercial efficiency are calculated for possible patterns and conditions of financing;
- Variants are compared based on individual power technology development rates and parameters of the project's commercial efficiency.

The algorithm considered above is intended for working out investment decisions in the event when power technologies have been already developed and the development of the power system in time based on these technologies is meant. However, practically the same algorithm may be used for a preliminary comparative analysis of the economic efficiency of power technologies in the course of the design, i.e. still before the decision is made to use them in particular power systems.

Calculation results for the individual rates Yi at the comparison of five NPP technologies are presented in Fig.11 for the rates of 0≤Y≤5 %/year.

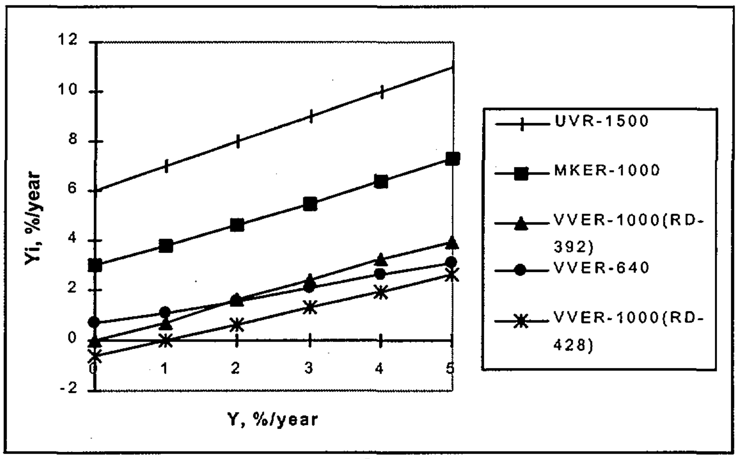

Fig.11. Values of individual rate Yi for different technologies relatively VVER-1000(RD-392) technology rate of development Y (E=1%/year).

The values of Y_i presented in Fig.11 are actually the dividends the investor can get if he invests his capital in the i-th technology at the specified (predicted) demand for electric power (Y value). However, the fact should be always taken into account that after any technology becomes a monopoly, its individual rate will turn out to be equal to the demand growth rate Y.

CONCLUSION

This paper has analyzed the existing methodical approaches to evaluating the comparative economic efficiency of investment projects in electric power. The used methods have been compared by a theoretical analysis of their economic content supported by practical evaluations using technical and economic characteristics of a number of power units. There have been noted drawbacks inherent in these methods that are first of all connected with the unsubstantiated use of the discount rate value (E≈10%/year) which leads to underestimation of the competitiveness of nuclear power installations. And the rated approach to price formation contradicts to the market economic mechanism of the functioning of the power industry ("deregulation") and does not stimulate introduction of advanced technologies as the fundamental economic principle of regulation of production and business activities.

This paper has presented a new methodical approach to analyzing the market economic mechanism and the system nature of the power industry functioning taking into account economic mechanisms of cooperation not only inside the technological system of power industry but also with adjoining branches, fuel and raw material industries first of all. It substantiates the discount rate as the obsolescence rate of the products which determines the selection of this indicator value. It is noted that the condition of an economically substantiated comparison of variants is consideration of the operation of power technologies in self-financing conditions as a single equilibrium price (tariff) is formed in the power system. Besides the coverage of all operating expenses, the price amount should ensure deductions for R&D and STP and renovation deductions for recovering depreciation of fixed assets and, the main thing, profit-making providing for construction of new generating facilities proceeding from the predicted level of power consumption in the country's economy.

Accordingly, the individual development rate of each power technology in the power system becomes the key one in evaluating the comparative efficiency. And no less competitive producers are rejected as it occurs in the currently used methods. It has been shown that the NPV, IRR, PI and DPP indicators widely used in the project analysis, are predominantly a function of the individual rate as the most dynamic criterion depending on the cost of the fixed assets and the expenses for the development of the fuel base and infrastructure of each industry.

The presented methodical approach has been shaped as an economic - general mathematical model and has been demonstrated on examples using technical and economic characteristics of particular NPP and CGPP projects.

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