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Criteria of return on investment in nuclear energy

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Abstract

Analytical relationships between the investment performance criteria (net present value (*NPV*), levelized cost of electricity (*LCOE*), internal rate of return (*IRR*), discounted payback period (T_{PB}), and discounted costs (Z)) and basic engineering-economic parameters of nuclear reactors (capital costs K, annual operating costs Y, annual revenue R, NPP construction T_C and operation T_E periods), characterizing the NPP profitability and competitiveness at the microeconomic level, are defined for the first time. The power function of discounted cash flows was used in calculations.

It is shown that the joint analysis of the entire set of investment efficiency criteria (not only *LCOE* as it is often done) can help avoid contradictions in assessing the NPP project profitability and formulate optimal requirements on the reactor engineering and economic parameters. The obtained analytical expressions provide solutions not only of the traditional «direct problem» (assessing efficiency criteria according to the forecasted capital and operating costs and profit stream) but, which is of equal importance, the solution of the «inverse problem»: assessing restrictions on capital and operating costs, i.e. identifying «investment corridors», based on the desired values of efficiency criteria.

The investment risk assessment results obtained by Monte-Carlo method are presented in order to account for the inherent uncertainties in the forecasts of long-term cash flow during the NPP construction and operation required for assessing the efficiency of investments. The calculation results of probability distributions of the investment efficiency (profitability) criteria are presented for the specified ranges of uncertainties the forecasted cash flow. It is shown that the risk of project unprofitability can be quite high. In order to reduce investment risks, it is necessary to justify the changes in basic reactor parameters (decrease in K, Y, T_C and increase in R and T_E) and uncertainty ranges in the initial data.

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Keywords: Investment efficiency criteria; Nuclear energy; Nuclear power reactor; Capital and operating costs; Revenues; Discount rate; NPP competitiveness; Monte-Carlo method.

Introduction

The conditions of stiff competition between the companies offering Generation III and Generation III+ nuclear power reactors are currently being shaped on the global oligopolistic NPP construction market [1–3]. A number of criteria (indicators) are used for assessing competitiveness of different reactor design projects which can be subdivided into the following levels: microlevel, mesolevel and macrolevel [4,5]. However, the primary "nucleus" of the system of indicators of competitiveness of the NPP construction project is the set of technical and financial parameters of the nuclear power reactor which ensures investment attractiveness of the project, i.e. its guaranteed return on investment or profitability (microlevel).

After publication in 2000 of IAEA guidelines [6] on the economic assessment of tender offers as pertains the NPP construction on the basis of "discounted cost of electricity" during the whole lifecycle of electric power generation facility *LCOE* (levelized cost of electricity) the *LCOE* value representing the minimum cost of produced and delivered electricity becomes both in Russian and in foreign literature the main criterion of competitiveness of construction of power plants of different types [7–12]. However, the so-called "net present value" *NPV* [1,13–18] serves as the principal crite-

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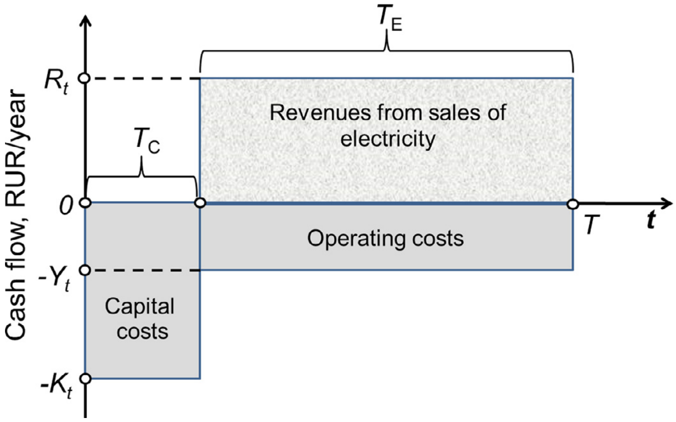

Fig. 1. Base layout of expected annual cash flows within the investment project (power plant construction and operation) throughout the whole lifecycle duration *T*.

rion of profitability of investment project. In this case, other auxiliary criteria such as the levelized cost of electricity *LCOE*, internal rate of return (*IRR*) and discounted payback period (T_{PB}) follow from the mathematical definition of the net present value. Emphasis laid in a number of publications solely on the levelized cost of electricity, which is, of course, a very convenient parameter for comparison of different power generation facilities, may result in the controversy with the criterion of profitability of the project *NPV*. In a number of studies, for instance, in [11,12,19,20], *NPV*, *LCOE* and *IRR* criteria are discussed in the economic analysis of NPP projects, but, however, their mutual interference has not yet been investigated.

Therefore, the purpose of the present study is the determination of the analytical interrelation between technical and financial parameters of nuclear reactors and the criteria of efficiency of investments in NPP construction characterizing competitiveness (payback) of NPP on microeconomic level. Results of assessment of investment risks for NPP construction project using Monte-Carlo method are presented in connection with uncertainties inherent in the long-term forecasting of cash flows during construction and operation of NPPs required for assessing efficiency of investments.

Net present value

Net present value *NPV* (in rubles) is the "net discounted profit" [1,6,8,13–16] accrued (summed up) during the whole lifecycle *T* (years). Taking into account that annual monetary expenditures (runoffs) $C_t = K_t + Y_t$ (RUR/year) are divided for the sake of convenience of analysis into the following two components – *capital costs* K_t and *operating costs* Y_t (for example, as in Fig. 1), general expression for *NPV* is split into two parts with different limits of summation as follows:

$$NPV = \sum_{t=1}^{T} \frac{R_t - C_t}{(1+p)^t} = -\sum_{t=1}^{T_C} \frac{K_t}{(1+p)^t} + \sum_{T_C+1}^{T} \frac{R_t - Y_t}{(1+p)^t}. \quad (1)$$

Here, R_t–C_t is the net profit during year *t* defined as the difference between the expected annual revenue flow R_t and the expected costs flow C_t. Each annual difference (R_t–C_t) is reduced to the starting moment by multiplication by the reduction factor (present value index) $(1+p)^{-t}$. The value *p* (1/year) is the discount rate (norm). This value characterizes the annual profitability of the project similarly to the profitability (interest rate) of a bank account (deposit) and must exceed the cost of capital attracted as investments. There exist numerous guidelines on the selection of discount rates taking into account inflation, investment risks and other factors influencing the profitability of the project [6,8,11,12,17,18]. Similar discount rates equal to 3, 5 (or 7) and 10%/year are often used abroad for preliminary comparative assessments of different power generation projects [9,19,18]. It is clear from formula (1) that capital costs are taken into account only during the period of construction of the object covering the time period with duration equal to T_C, i.e. the period from $t=0$ to $t=T_C$ (see Fig. 1), while operating costs Y_t, as well as revenues R_t are accounted only during the process of operation with duration equal to T_E, i.e. from the time moment $t=T_C$ to $t=T\equiv T_C+T_E$. The moment to which reduction is made in formula (1) is the first year of the project. The first year of operation of the object is taken in a number of publications as the year to which the reduction is made. Result of *NPV* calculation is not dependent on the choice of the year to which the reduction is made.

*Investments with the highest positive net present value (*non-negative, i.e. with accrued profit*) are preferable*. In other words, investment costs for the construction of NPP must be covered and repaid from the revenues coming from generated and sold electricity. Consequently, the sign of *NPV* criterion means that the project is profitable ($NPV > 0$) or loss-making ($NPV < 0$) by the end of its lifecycle. When $NPV = 0$ the cost of the project is paid back only by the moment of completion of its lifecycle which may exceed 100 years for NPP.

Let us note that the purpose of *NPV* is solely for determining the conditions of project's profitability. Distribution of profit generated in the process of implementation of investment project is a completely different task not addressed in the present study (see Refs. [14,15,21,22]).

Let us examine first the ideal (best) scenario of the project in the approximation "fast construction when $T_C \to 0$ and extended period of operation when $T \approx T_E \to \infty$", which provides clear and straightforward relations for the criteria. Let us assume for the sake of simplicity that annual revenues and operating costs are constant and are equal, respectively, to $R_t = R$ and $Y_t = Y$ (base option). Then, the first sum on the right side of (1) is the total capital costs (–*K*), while the second sum represents the infinite converging geometric progression with progression ratio equal to $q = (1+p)^{-1}$ and the sum of the progression equal to (*R*–*Y*)/*p*. As the result, for the given technical and financial parameters of power reactor (*K*, *Y*, *R*) we obtain the highest value for *NPV*:

$$NPV \le -K + (R - Y)/p. \quad (2)$$

In the general case for specific duration of NPP construction T_C (year) and operation T_E (years), we obtain from (1) instead of (2) the following expression which is convenient

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