Study of the economic viability of the innovative nuclear reactor SMART in Brazil

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ABSTRACT

The main objective of this study is to evaluate the economic viability of the installation and operation of the innovative System - Integrated Modular Advanced Reactor (SMART) in Brazil. SMART, developed by the Korea Atomic Energy Research Institute (KAERI), is a small and modular Power Water Reactor (PWR), presents electric power of 100 MW and thermal power of 330 MW; it has a passive safety system and integral refrigeration configuration, characteristics that, allied with modularization, simplification and technological improvements, give SMART greater reliability and economy when compared to conventional reactors. SMART presents, in addition to electricity production, the functions of seawater desalination and district heat generation.

The research is based on projections of energy demand in the medium and long term with emphasis on electricity and search for the reduction of greenhouse gases. These previsions indicate the need for energy expansion and diversification of the current sources in Brazil, predominantly water sources.
The methodology used is based on the cost of electric generation, production capacity and construction time of SMART, adopting the investment model similar to the Angra 3 plant and the use of mirrored costs between the plants.

The feasibility of the project was evaluated through the financial criteria: Internal Rate of Return (IRR), Net Present Value (NPV) and Weighted Average Cost of Capital (WACC), whose revenue should be generated through a tariff passed on to the consumer.

1. INTRODUCTION

The growing global concern about the supply of energy in a medium and long term horizon has mobilized companies in the energy sector to carry out studies on energy consumption in Brazil and worldwide [1].

These studies indicate that Brazilian energy demand may double by 2050 [2] observing a significant increase in electricity; still according to these studies, oil and hydro energy demand space, natural gas must increase and wind, biomass and nuclear energy tend to become more relevant [3].

Nuclear energy as a source of electricity has been gradually defended by environmentalists as it is considered "clean" and causes a low level of environmental impacts, thus, contributing to the mitigation of the climatic effects to the planet.

Brazil in particular has the additional advantages of the abundance of raw material (uranium and thorium) and the field of fuel cycle technology currently applied to the PWR reactors of the plants in operation, Angra 1 and Angra 2 and in the future to the plant Angra 3 [4].

The biggest problems faced by nuclear energy today and highly questioned by populations around the world refer to the high costs of installing reactors and the risk of accidents.

Innovative nuclear reactors arise in response to these disadvantages by bringing a much higher safety and economy proposition than conventional reactors. Its main innovations are the safety systems that guarantee core cooling even in the event of operating failures and technology improvements that allow greater automation, less stopsfor refuelling and less tailings production; reduction of construction time with faster return of capital and rational use of fuel [5].

Among the various types of reactors currently in operation or being researched, the following stand out:

• generation IV, from small to medium and modular; are Small Modular Reactors (SMR), whose power ranges from 100 to 625 MW, and can reach 1300 MW when grouped; SMART is an example of such reactors [6].

• generation III + with several improvements; examples are AP1000 of Westinghouse and European Pressurized Reactor (EPR) of AREVA [7].

• High Temperature Gas Reactor (HTGR) gas-cooled that operate at high temperatures; an example is Pebble Bed Modular Reactor (PMBR), moderate to graphite and gas-cooled (CO_2 or He) in which the heat generated by high temperature steam can produce pure hydrogen by hydrolysis [8].

• Rapid Fast Breeder Reactor (FBR), also called breeder for producing fuel as they consume through fast neutrons; Example: Liquid Metal Fast Breeder Reactor (LMFBR) cooled to liquid sodium [9].

• Type sub-critical Accelerator Driven Systems (ADS) that use neutrons from a particle accelerator coupled to the reactor and "burn" waste reducing the half-life of radioactive elements, from millions to hundreds of years. As an example we have the research reactor in Mol, Multipurpose Hybrid Research Reactor for High-tech Applications (MYRRHA) [10,11].

The present research adopts criteria of economic-financial analysis used in feasibility studies for the implementation of the SMART reactor in Brazil, which are:

• Internal Rate of Return (IRR): is the rate required to equal the value of an investment (present value) with its respective future cash balances generated in each period; being used in investment analysis, means the rate of return of a project.

• Net Present Value (NPV): is the sum of the present values of the estimated flows of an application calculated from a rate and its duration period. If the NPV is negative, the project return will be less than the initial investment indicating the project's unfeasibility and, if it is positive, the value obtained in the project will pay the initial investment, making it viable [12, 13].

• Weighted Average Cost of Capital (WACC): is the rate that measures the remuneration of the capital invested in a particular enterprise and varies for each company. In the case of evaluating the viability of new projects, functioning as a "minimum rate" to be exceeded to justify its investment [12, 14].

2. MATERIALS AND METHODS

The System-Integrated Modular Advanced Reactor, SMART, was selected to be installed in Brazil as it is an advanced reactor, presenting several innovative advantages as described below, but also conserving the PWR operation, similar to the reactors already known in Brazil as Angra 1, 2 and 3. The economic viability techniques IRR, NPV and WACC were applied.

2.1. SMART Overview and technical aspects

The SMART is a small to medium-sized, PWR, refrigerated and light-water-moderated advanced reactor with a thermal capacity of 330 MW and a 100 MW electrical capacity whose project, started in 1997, was developed by Korea Atomic Energy Institute (KAERI).

The increase in safety is due to innovative design aspects such as the complete configuration of the refrigeration system, improved natural circulation capacity, passive residual heat removal system and consequent minimization of the risk of nuclear accidents. The gain in the economy is due to simplifications in systems, modularization of components, short-term implementation and maximized production.

The low power density of the core provides a thermal margin above 15% accommodating any transients in the heat flow and ensuring the thermal reliability of the core in normal operation.

The chain reaction is controlled by control bars and soluble boron; The four-channel position indicators on the bars contribute to the enhancement of the core protection system..

The medium refrigerant temperature program maintains the temperature almost constant at all points of the primary flow and the stable pressure in the water of the pressurizer.

The integrated arrangement of primary components such as pressurizer, steam generators and cooling pumps in the reactor vessel allows for simplification of the set of pipes, reducing the number of connections and improving the flow of refrigerant.

Steam generators consist of heat transfer tubes helically wound to produce steam at 30° C under normal operating conditions.

Preliminary safety analyzes and thermohydraulic tests have been conducted demonstrating the effectiveness of SMART's technical systems and estimate that the amount of water and electricity produced is sufficient to supply a population of about 100.000.

The economic improvement of SMART over conventional reactors is mainly due to a smaller number of tubes and valves, component standardization, modularization, direct manufacturing and installation of suppliers and reduction of construction cost.

The SMART project includes, in addition to electricity generation, the functions of desalination of sea water and the generation of heat for district heating [15].
Figure 1 below shows a cross-sectional drawing of the SMART primary circuit, indicating its main components contained in a single pressurizing vessel

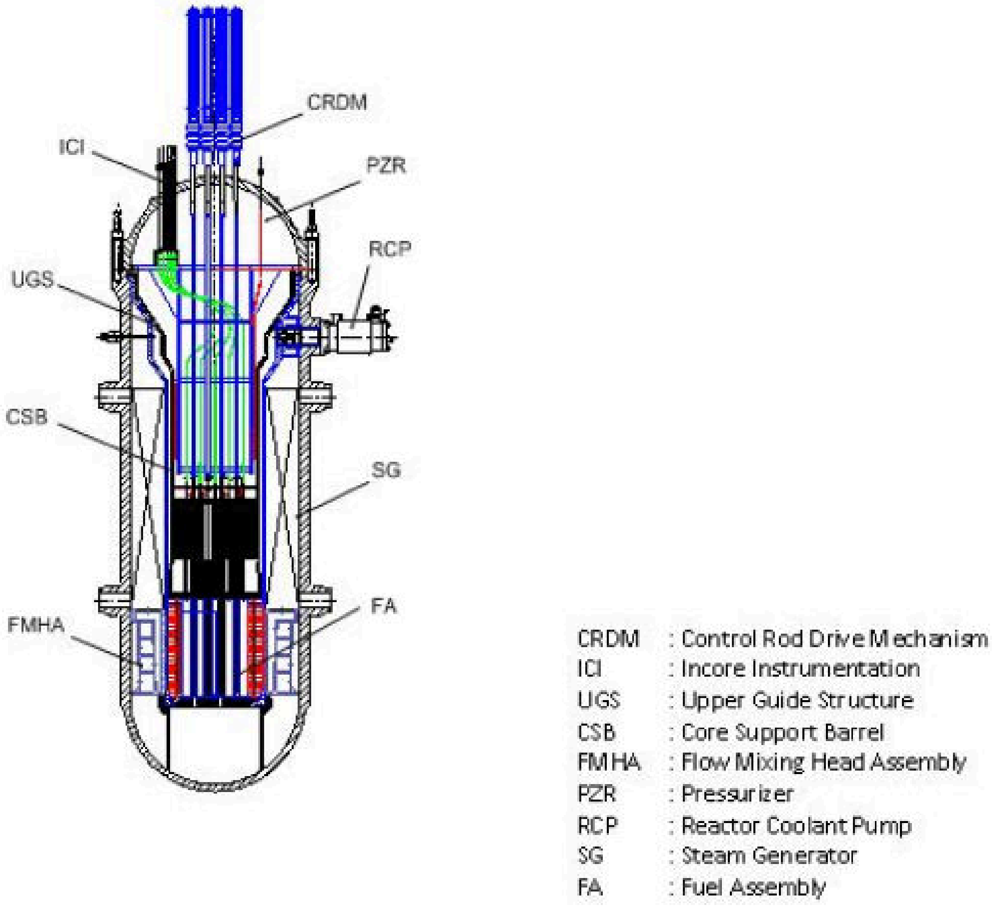


Figure 1 - Schematic drawing of the primary circuit (ref. 15)

2.1.1 Fuel management

The SMART core contains 57 fuel assemblies in a 17x17 matrix whose design is characterized by:

• operation of longer cycles with recharging of two lots;

• low power density;

• thermal margin above 15%;

• Minimum movement of the stem for recharging followed by control of the coolant temperature.

SMART fuel management is designed to achieve a maximum period between two consecutive refueling. A simple two-batch scheme without reprocessing returns a cycle of 990 full-power effective days for a 36-month operation.
This recharging scheme rationalizes fuel utilization and presents flexibility in meeting demand requirements [6,15].

Figure 2 shows the schematic drawing of a typical 17x17 fuel assembly used in SMART.

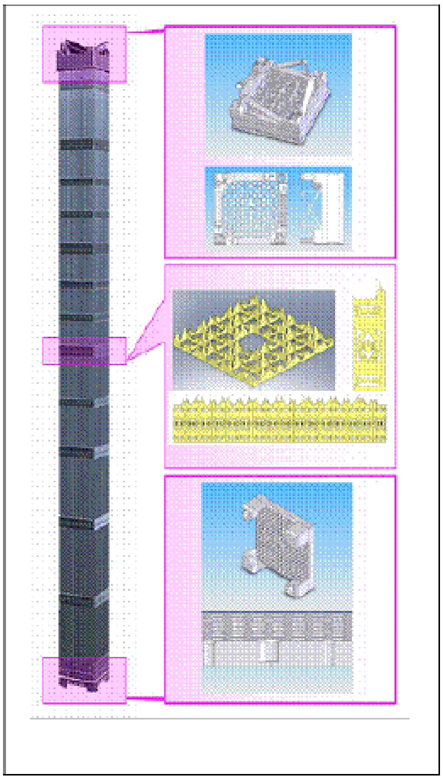


Figure 2 - Fuel matrix 17x17 (ref. 15)

2.2. Economic-financial analysis of SMART implementation

In order to evaluate the economic viability of the SMART reactor installation project, the mirrored data technique was applied using as reference the value invested in the Angra 3 plant, correcting it by inflation [16], considering the real construction time equal to 96 months and applying the proportionality to the "ideal" construction time, which would be 66 months (5.5 years), as predicted in the initial contract in 1984. Thus, the value of investment VI was obtained and a parameter of comparison of costs between the two plants was established.

For the calculation of the total cost were listed the main costs involved in the project: construction; operation and maintenance; equipment, decommissioning, depreciation, insurance, environmental protection, direct expropriation, interest and Human Resources [17].

Several items were collected directly from sources corresponding to references [18], [19] and [20] and others resulted from financial calculations adopting the following parameters: Plant life = 40 years; interest rate = 10.25% per year; decommissioning = 10% of the construction cost; direct depreciation = 10% per year; insurance = 1% of the construction cost per year [21].
Applying the accounting principle of conservatism, the costs are supposed to have risen slightly compared to the usual [22].

To generate the revenue, the following data was used:

SMART electric generation cost = US$ 4.06 cents/MW updated to 2017 [16]; Factor of capacity FC = 80,06% and generation capacity = 90 MWh [6].

The following criteria were covered:

• WACC of 10% per year, which is the average rate of credit operations carried out by the National Economic and Social Development Bank (BNDES).

• 5 years of construction of both plants, used to establish a standard of comparison. It is assumed that, although the expected construction time for the SMART plant is 3 years, there is usually an extension of the term according to the current environmental legislation [22].
The present analysis disregards factors related to taxes and rates.

3. RESULTS AND DISCUSSIONS

The amount of VI investment calculated was approximately R$ 3.5 billion and the revenue generated was R $ 26.98 billion (approximately R$ 27 billion).

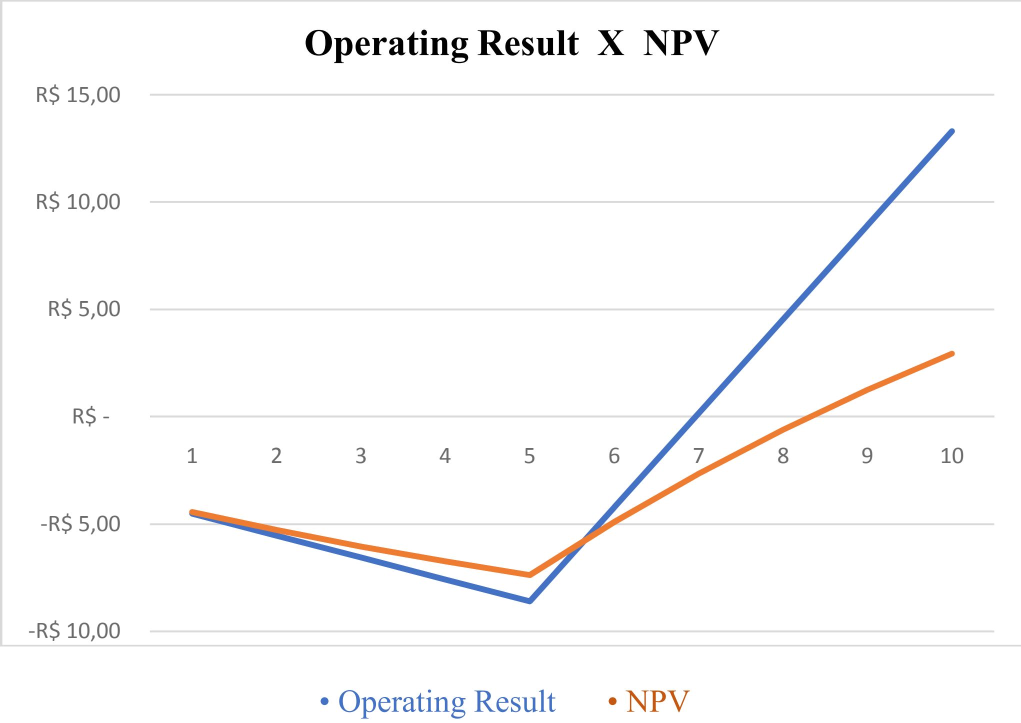
The cash flow was made showing gross revenue, net revenue, totals, operational result, NPV and IRR over 10 years, being 5 years of construction and 5 post-construction for the revenue evaluation at an estimated total cost at approximately R$ 10,20 billion.

The table below shows the cash flow sheet in billions of reais (table 1) and the graphs: "Operating Result x NPV" in years x R$ (graphic 1) over the 10 years and "WACC x IRR" in units % x (graphic 2)

Table 1 - Cash Flow

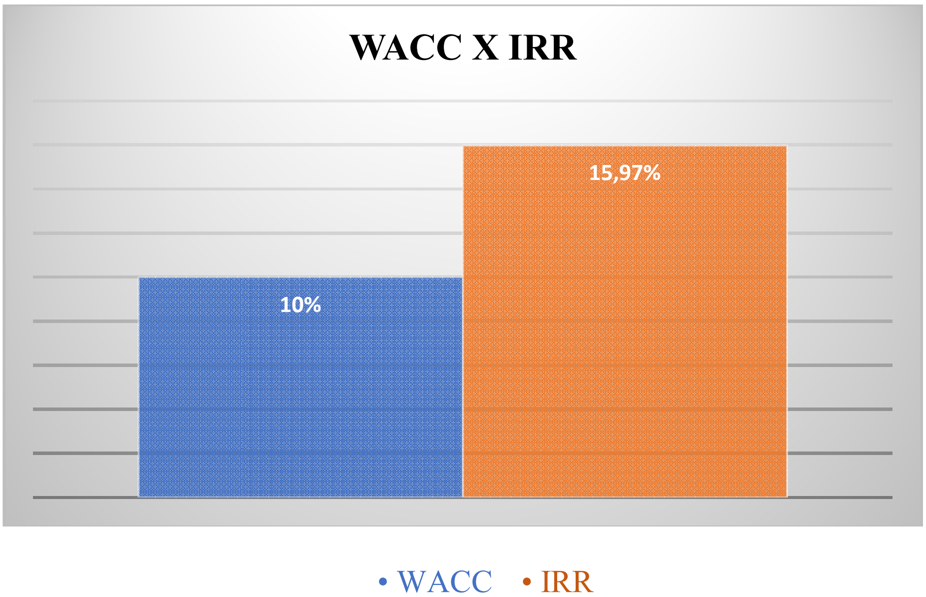
YEAR	GROSS REVENUE (R$)	COST (R$)	NET REVENUE (R$)	OPERATING RESULT (R$)	NPV (R$)
1	-	1,02	-1,02	-4,52	-4,43
2	-	1,02	-1,02	-5,54	-5,27
3	-	1,02	-1,02	-6,56	-6,04
4	-	1,02	-1,02	-7,58	-6,73
5	-	1,02	-1,02	-8,60	-7,37
6	5,40	1,02	4,38	-4,22	-4,89
7	5,40	1,02	4,38	0,16	-2,65
8	5,40	1,02	4,38	4,54	-0,60
9	5,40	1,02	4,38	8,92	1,25
10	5,40	1,02	4,38	13,30	2,94
TOTAL	27,00	10,20	16,80		IRR 15,97%

The table 1 shows Operating Result via WACC accumulated of R$ 13,30 billion; NPV of R$ 2,94 billion and IRR = 15.97% per year, at the end of the period.



Graphic 1 - Operating Result X NPV

The graphic 1 shows both increasing curves after the 5th year, marking the end of the investment period and the beginning of revenue generation. Indicates positive returns: Operational Result from the 7th year, 2 years after construction and the NPV, between 8th and 9th years, which corresponds to Pay Back equal to 8 years, 1 month and 20 days. This is the moment at which, after deducting cash interest, the money invested is returned.



Graphic 2 - WACC x IRR

Graphic 2 from IRR in relation to the WACC used in the investment shows that the financial cost is 10% per year and the project will bring a return of 15,97% per year.

4. CONCLUSIONS

By adopting the same criteria of the Angra 3 plant for the SMART plant and respecting the 5 years of construction, the project is widely feasible with a satisfactory pre-operational return.

It is worth noting that the present analysis disregards factors related to taxes and rates.

The comparison between total cost and net revenue shows that the revenue generated by electricity and the tariff charged is much higher than the costs, making the project viable and opening the financial margin for new investments.

The results obtained in this research provide a pre-assessment of the economic feasibility of implementing a SMART nuclear power plant in Brazil today using projected values.

It is suggested, for future work, a more in-depth analysis through the collection of data with a greater degree of precision.

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