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Small modular reactors: Methodology of economic assessment focused on incremental construction and gradual shutdown options

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ABSTRACT

Small modular reactors (SMR) inherently offer two considerable options to improve their economics via module management: incremental construction and gradual shutdown.

Incremental construction presumes the initial construction with fewer modules than available reactor bays at the plant. Further modules are purchased under favourable conditions later to improve the economics of the power plant. Although this approach results in worse economic indicators, the financial feasibility of the plant is viable due to the lower initial investment. Gradual shutdown option is applied when electricity price deteriorates and modules assigned to supply electricity are temporarily shut down.

These options were applied to case study based on the NuScale reactor placed onto one of nowadays European electricity markets. Initial number of modules was set to 10 out of 12 reactor bays. Monte Carlo technique was employed in order to deal with stochastic nature of the economic environment.

Deliverables confirmed that incremental construction and gradual shutdown improve the economics of the small modular reactors. Moreover it may save the feasibility of the project through achieving the balance between funding and economic effectiveness. Present value of these options concerning examined case study reaches approximately 300 mil. EUR and under favourable conditions up to ca. 600 mil. EUR.

1. Introduction

The transition from regulated to open European electricity markets and their subsequent distortion through heavy subsidies suppressed the overall operators' revenue. Moreover the regulation parameters are changing and even the whole regulatory frameworks are transformed from time to time. Such unstable environment can indulge rapid changes in the price of electricity. That would then result in deterioration of the projects' profitability, being in liberalized environment the main motivation.

In these turbulent conditions the investor or operator can hardly predict the economics of a century lasting project. Nuclear stakeholders recognize current situation as unsustainable, hence they are finding alternative technologies, investment models and new (lawful) ways of financing.

Interest in small modular reactors (SMR) is on a rise, with more convincing clues indicating that SMR technology has the real potential to be deployable worldwide. Besides the long-term strategies to incorporate SMRs into power systems in many countries, particular examples do exist. It should be mentioned that the first ever application for design certification of SMR in the USA (NuScale) has been submitted (https://www.nrc.gov/react, 2017) and the effort of Great Britain to „establish UK as a global leader in the SMR market“ stated House of Commons in (Members of Energy and Climate Change Committee, 2016) and was confirmed by UK government in December 2016 (https://publications.parl, 2017).

Taking into account the mix of dismal unsustainable market situation, increased need for spinning power sources in the grid induced by intermittent sources and further positive externalities of SMRs like zero emissions, heat supply option, reduced emergency planning zones, inherent safety or reduced operation and maintenance costs, we may say that SMRs are strong candidates for the source of tomorrow. In fact there is only one weakness of SMR today – the economy.

Even though SMR investments are less demanding than those of large reactors, SMRs still bear high risks because they are new technology with slightly higher specific investment costs and almost no operational experience. It may be anticipated that these risks will increase the price of projects' financing.

These considerations lead us to the crucial questions: Is it possible to reduce SMR projects' risks? What if the investor is not able to ensure the financing for the whole project? Would it be feasible to install less than full number of modules to the reactor slots?

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2. Bibliography review

According to available resources, the main disadvantage of small reactors is the absence of economy of scale. However, this handicap may be compensated by economy of multiples and steeper learning curve. Article (Carelli et al., 2007) states that common N_{th} of a kind (NOAK) price of reactors is obtained after the installation of 5–7 units regardless their power output. Therefore, a lot of SMRs could take the advantage of the common investment costs meanwhile large reactors would be still facing higher prices because their learning curve would not flatten so quickly. Moreover the risk of cost overruns is minimized due to the modular construction (Carelli et al., 2008; Solan et al., 2010; Welling, 2010; Locatelli and Mancini, 2010).

Notable advantage of SMRs deployment is their size, which enables their utilization even in small power systems. Also due to significantly reduced emergency planning, these reactors can fit to a place with high density of population. Shorter distance between generation of heat and final consumption provides profitable heat supply according to (Carelli et al, 2007, 2010; Locatelli et al., 2014, 2015). In addition (Carelli et al., 2007), and (Locatelli et al., 2013) concluded that SMRs are excellent solution for developing countries, particularly areas with lack of drinking water as of many SMR designs have the capability of producing potable water. Another advantage of small reactors is better achievability of financing comparing to large reactors and therefore SMR could become feasible even for private investors.

Another benefit is decreasing the risk of SMR investments via flexibility in adaption to market condition and incremental construction. However the majority of available papers consider predominantly real option instruments in construction phase, e.g. (Gollier et al., 2005) is focused on power plant construction abandonment, once the market conditions deteriorate. Further on, a situation of interrupted operation generally of all types of power plants is described by (Roques et al., 2006).

Incremental construction consists of building the power plant with fewer modules than in the unit available slots. The rest of the modules are ordered later under favourable conditions and are partially financed by revenue brought in through the original modules. This is so called self-financing system (Locatelli et al., 2014, 2015). Described option is theoretically conceived, but very low interest is attracted to its evaluation, although it is the tool inherently given to small modular reactors and shall be taken to the account.

Gradual shutdown is a response to the low electricity price, when only modules used for own consumption and modules providing the mandatory supply are left in operation and others are shut down to save variable costs.

3. New methodology

According to (Roques et al., 2006) the operating flexibility option[1] value can be defined as the difference between the Net Present Value (NPV) of the power plant with and without application of operating flexibility option (further on denotes as ΔNPV). The idea of the method is to put the SMR in a specified economic environment and to apply two different managerial approaches:

- Basic approach keeps predefined operational regime, operational investments are made only within the scope of necessary maintenance and incremental construction is disabled. Basic approach represents non-dynamic NPV model with constant escalation formulas.
- Optimal approach starts with predefined operational regime that changes according to electricity price and operational cost swings. The purchase of new modules is done once the criteria of economic effectiveness are met with respect to some restrictions, e.g. the utilization of all slots of the power plant, the upcoming end of lifetime of the NPP when the module would not repay itself or in the initial years of the project when the loan have to be paid. Gradual shutdown option is applied when variable costs become higher than sales.

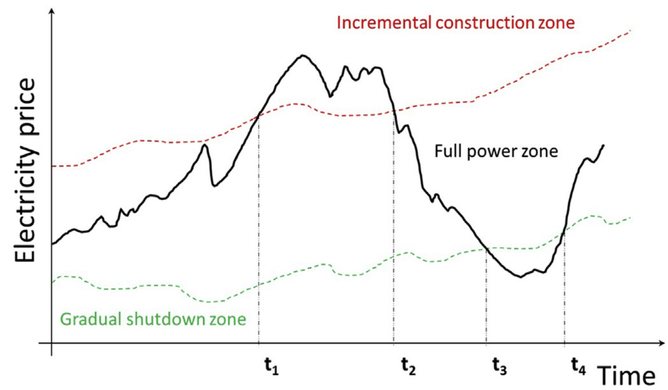

Fig. 1. Real options of the SMR against electricity price (not real data).

For simplified explanation of application of the options see Fig. 1. Dotted lines are threshold electricity prices for the application of the options and black solid line is the electricity price.

The methodology is based on inherent capability of SMR to perform Module management to use incremental construction and gradual shutdown.

Method is based on standard NPV model with objective function:

$$maximize\ NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t} \tag{1}$$

Where:

NPV: Net Present Value
CF: Cash Flow
T: Lifetime of the project (the end of decommissioning)
r: Discount rate (or WACC, depends on financing mode)
t: time

Generally there are two vital assumptions for SMR project realization:

$$NPV \geq 0 \tag{2}$$

$$CF_0 \geq INV_{max} \tag{3}$$

Where:

NPV: Net Present Value
CF_0: The sum of Cash Flow before operation commencement
INV_{max}: Available financing sources (Equity and Debt)

The criterion (2) is purely economic, representing the required profit from invested capital and assumption (3) secures the financial feasibility of the project. In other words, the project with higher number of modules should achieve better economic results, in consequence of smaller cost share per production unit regarding balance of plant and induced investments. On the other hand such project is more difficult to finance and constraint (3) may not be satisfied.

Simplified chart (Fig. 2) shows the situation, where the incremental construction[2] may save the SMRs' feasibility. Green solid line shows the

[1] Incremental construction is performed during the operation phase, thus it may be considered as operating option even though it does not affect the operation of each module.

[2] Gradual shutdown option is expected to bring smaller contribution than incremental construction and in the chart may be omitted.