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Nuclear Power as an Option in Electrical Generation Planning for Small Economy and Electricity Grid

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ABSTRACT

Implementing a NPP in countries with relatively small total GDP (small economy) and usually with small electricity grid face two major problems and constrains: the ability to obtain the considerable financial resources required on reasonable terms and to connect large NPP to small electricity grid.

Nuclear generation financing in developing countries involves complex issues that need to be fully understood and dealt with by all the parties involved. Besides conventional approaches for financing power generation projects in developing countries, recently some alternative approaches for mobilizing financial resources are developed.

The safe and economic operation of a nuclear power plant (NPP) requires the plant to be connected to an electrical grid system that has adequate capacity for exporting the power from the NPP, and for providing a reliable electrical supply to the NPP for safe start-up, operation and normal or emergency shut-down of the plant. Connection of any large new power plant to the electrical grid system in a country may require significant modification and strengthening of the grid system, but for NPPs there may be added requirements to the structure of the grid system and the way it is controlled and maintained to ensure adequate reliability.

Paper shows the comparative assesment of NPP adn differrent base load technologies as an option in electrical generation planning for small economy and electricity grid

1 INTRODUCTION

Energy in general and electricity in particular, is essential for economic and social development, prosperity, health and security of citizens: GDP is also closely related to energy consumption/cost/quality of supply. Countries must meet its rising energy demand without environmental damage, reducing harmful emissions and securing a stable and sustainable energy supply, and without excessive price or availability fluctuations. The many energy sector currently faces three major challenges: ensuring security of energy supply; reducing greenhouse gases (GHG) emissions and maintaining economic competitiveness by keeping energy prices at an affordable level. Making decisions on the future energy mix will depend on national goals and priorities, on exploration for fossil resources, on the development of clean coal and carbon capture and storage technologies, on improving the performance and cost of renewables, energy efficiency or placing greater reliance on imports. The only base load generation option available today, with low carbon emissions comparable to nuclear power (NPP) is large hydropower, but its contribution in meeting the energy demand in many cases cannot be much greater than that at present as most of its potential as already been exploited. NPP do not emit greenhouse gases. Already, due to low cost fuel and improved efficiency, nuclear plants once built can be less expensive to operate. Thus, even in a marketplace that does not credit its virtues, nuclear power is increasingly competitive. Putting a tag on harmful emissions would quickly make nuclear power the cheapest option as well as the

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cleanest for generating increasing energy in the global scale. New NPPs could make an important contribution, to meeting needs for low carbon electricity generation and energy security in this period and beyond to 2050. Many countries are and will face a great deal of uncertainty about energy supplies over the next couple of decades. But there are also uncertainties relating to future fossil fuel and carbon prices; the speed at which we can achieve greater energy efficiency and therefore likely levels of energy demand here and globally; the speed, direction and future economics of development in the renewable sector; and the technical feasibility and costs associated with applying carbon capture and storage technologies to electricity generation on a commercial scale. Faced with these uncertainties we need diversity and flexibility in the energy mix and a policy framework that opens up the full range of low carbon options. The best way to achieve secure energy supplies is by encouraging a diversified mix of generating technologies. Giving energy companies the option of investing in new NPP lowers the costs and risks associated with achieving our energy goals to tackle climate change and ensure energy security.

Making the decision to embark upon a nuclear power program is a major undertaking for any country. Such a decision involves careful planning, as well as a long-term commitment to the nuclear power program. It is significant commitment in terms of time and resources (both human and financial). The process involves the development of a nuclear power project within the overall national program; consequently, the host government must consider both the NPP and the supporting infrastructure for the NPP. Such infrastructure must include legal, regulatory, technological, human resources, and industrial support.

The experience of the NPP projects already implemented showed that a major requirement for, and constraint to, the development of NPP projects in developing countries is the ability to obtain the considerable financial resources required on reasonable terms. As nuclear generation financing in developing countries involves complex issues that need to be fully understood and dealt with by all the parties involved. The financing of such projects presents a critical problem not only because of the very large amount of financing needed, but also because of the relatively low creditworthiness of country as perceived by various lending organizations. Consideration should be given to the principal characteristics specific to nuclear power projects, as well as to the overall complexities of such projects and how these complexities affect their financing. It is essential that every effort be made by all parties involved in the development of a nuclear power project to reduce the uncertainties linked to such large investments and long project times, in order to improve the overall climate for the financing of these projects. In order to successfully finance a nuclear power project, it is essential for the government/utility to prepare a thorough financial analysis, together with an economic analysis, for evaluating the feasibility of the project.

Today the question is which approach can be used to finance nuclear power plants to be compatible with current utility and financial market conditions and specially in small economy. The economics of nuclear power depend on national or even local conditions, including the costs of capital, labour and materials, the regulatory environment, and the availability and costs of alternative generating technologies. Increasingly, the economics of new nuclear power plants can, depending on location and alternatives, compare favourably with non-nuclear alternatives. The overall comparison also depends on values assigned to possible external costs, such as air pollution, greenhouse gas emissions, import dependence, cost uncertainties and the comparative risks of different alternatives. Also deeper understanding of the risks involved in project finance and risks evolution over time is important for both practitioners and policymakers. In particular, further research in this area might help in the implementation of risk sensitive capital requirements providing market participants with the incentives for a prudent and, at the same time, efficient allocation of resources across asset classes. This is particularly relevant, given the predominant role of internationally active banks in project finance and the fundamental contribution of project finance to economic growth, especially in emerging economies.

Now also should be studied how the risks specific to a nuclear power investment in liberalised markets can be mitigated, how they can be allocated to the different stakeholders, and which financial arrangements are consistent with the alternative allocations of the construction and operating risks. Under the former regulated utility regime and regulatory arrangements, many of the risks associated with power plant construction costs, operating performance, fuel price changes, and other factors were borne by consumers rather than investors. The current context for new nuclear build in power markets is significantly different with producers bearing much of the risks unless some are transferred onto other stakeholders through long term contracts and/or innovative financing arrangements.

1.1 Specificities of the Nuclear Industry

The decision of a country to embark on a nuclear power program entails a long-term commitment to the peaceful, safe, and secure use of nuclear technology, based on a sustainable organizational, regulatory, social, technological, and economic infrastructure.

The global financial system has recently experienced its worst crisis for several decades, with a number of major banks having failed or requiring large-scale government support. This is having a significant near-term impact on the ability to raise commercial finance for any purpose, including large-scale infrastructure like NPP. Significant risk transfers from plant investors onto governments, consumers, and for the first new reactors, onto vendors are likely to be needed to make nuclear power attractive to investors in liberalised markets.

Special features of nuclear power projects with respect to finance are: High capital cost, long construction period, Long term return on investment, Long term government commitment and public support (Plan, build, operate, decommission, waste management; Need to ensure funds for operation, maintenance, decommissioning and waste management) , Underpinning technical and human resource; Commercial risks (Credit rating of sponsor, Market, Competition, Schedule, Utility risk) , Economic risks (Inflation, Interest rates, Exchange rates, Political risks, Force majeure, Change in law); Government participation is seen as vital for a first unit in respect of non-design related ‘first of a kind’ issues (such as: First experience of regulatory process, Site preparation, Local supply chain and labour issues)

2 OVERVIEW OF CLASSICAL CONTRACTUAL AND OWNERSHIP APPROACHES FOR FIRST NPP

Looking at prior and current development of NPPs, development of NPP program has occurred either through sovereign-based structures or through corporate-based structures. This development history is one of leadership by public entities in a regulatory environment that enabled transfer of the significant development costs to an allocated customer base. Traditionally has been that owner/operator of the NPP was either government owned and/or regulated through the dedicated rate based that it serviced. As markets have liberalized, there is less opportunity to cover development costs through the rate base. Instead, potential NPPs need to be assessed on the strength of the underlying economics of the project within a competitive market structure.

Based on prior NPP development, project models have favoured the presence of a national or regional utility that has served as the owner/operator. Such owner/operator, either on the strength of its own balance sheet or through the support of sovereign funds, has provided the equity component for these NPPs, with debt financing (both commercial lending and Export Credit Agency financing) also based on balance sheet metrics and/or sovereign guarantees.

Historically, nuclear power development occurred either as part of a national power program that has been led by the host government or by national or regional utility companies that has been able to recover project costs through a regulated rate base.

2.1 Sovereign Model

In the case of the sovereign model, funding is provided through, or guaranteed by, sovereign sources, and ownership and operation of the NPP is through a government-owned utility [1]. Nuclear development is part of a national program, often evidenced by a national energy policy.

The strength of the sovereign model is that the program has the demonstrated support of the host government, with the ultimate credit behind the project being a sovereign credit. The critical aspect of the sovereign model is the underlying financing strength of the sovereign, either as financier or guarantor, to support the costs for the nuclear power program.

2.2 Utility Balance Sheet Model

In the absence of direct involvement of the sovereign, NPPs have been developed by utility companies, utilizing classic balance sheet financing for the nuclear power plants [1] . A national or regional utility serves as the developer of the project, financing the project based on the strength of the utility's balance sheet. Under historical models, such utilities operated within regulated power markets, thereby having the ability to recover project costs through a regulated rated of return.

By having a dedicated market for the power and a fixed rate of return (which was established by law), the regulated utility was able to assume project development risks and absorb cost overruns, recognizing that the project costs would ultimately get passed through to the rate base.

However, as electricity markets have been liberalized in many countries, the ability to structure rate-based projects has been minimized. Furthermore, given the multi-billion dollar cost to develop a NPP project involving in the range of 1100 – 1700 MWe, many utilities might not be large enough to assume the costs of one or more projects without placing the company at risk.

While long-term power purchase agreements could provide a substitute for the regulated rate-base approach. Without the ability to assure long-term off-take at pre-determined pricing, the utility might not be willing to develop a project and rely on market pricing to provide the expected rate of return on the investment.

2.3 Contracting new NPP

Distinct from the issue of ownership is the method by which the project will be delivered. Three main approaches have been used. In each case, the owner finances the project [1].

First, the owner can acquire the nuclear unit under an engineering, procurement, and construction (EPC) contracting approach, whereby the owner enters into a contract with a major engineering and construction firm that will deliver both the NSSS technology and construct the facility (also know as a "turnkey" approach). Under this approach, the owner monitors the project, but the owner is looking to the EPC Contractor to deliver the project under the terms of the EPC contract.

Second, the owner can divide the procurement based on the three main elements of the plant: the nuclear island, the turbine island, and the balance of plant. Under this split-package approach, also possibly mixing foreign delivery (nuclear island) with domestic delivery (balance of plant and, perhaps, turbine island).

Third, the owner can serve as architect-engineer, whereby it enters into a myriad of contracts for various services (engineering, design and construction) and equipment. Under this approach, the owner must have the internal capability to integrate this multi-faceted contracting approach. It is probably not an approach that could be employed by an owner looking to develop its first NPP.

2.4 Description of alternative new contracting models - BOO/BOOT

As possible new concept for developing NPP project can be Build-Own-Operate (BOO) or a Build-Own-Operate-Transfer (BOOT) structure. The host government first makes a determination that a non-government entity will develop the infrastructure project. BOO and BOOT models have been used successfully in a variety of infrastructure projects, a BOO(T) structure had not been attempted in the nuclear sector. Under such structures, the Developer is responsible for bringing together project development capabilities, to include: Technology; Engineering, Procurement, and Construction; Fuel Supply; Operations; and Financing.

Very simply, the BOO(T) structure places the responsibility for "bringing the project to market" on the Developer.

3 HIGH FINANCING COSTS FOR NEW NUCLEAR CONSTRUCTION

Factors contributing to high financing costs for new nuclear construction are: interest rate that includes a risk premium; credit rating of utility; inability to pre-charge rate payers without backlash; duration of project; cash on hand; risk premiums charged by banks.

Utilities are subjected to paying an interest rate that includes a risk premium for loans to build new nuclear power plants. Banks argue that the uncertainty associated with new nuclear construction warrants a higher interest rate than market rate. The uncertainty banks are referring to is whether or not the nuclear power plant will ever be completed, and if it is, whether or not the plant will receive an operating license from the nuclear regulator. These risk factors allow the banks to make a case that the interest rate on loans for new nuclear construction should be several percentage points higher than market rates because the utility company may never get the cash flow benefit from the project should it not obtain an operating license or the construction is not completed. Every business has a different credit rating and banks charge businesses with a lower credit rating a higher interest rate than businesses with higher credit ratings and each company's individual credit rating will affect the interest rate they obtain on the loan(s) from the bank(s).

Every utility company will choose a different financing structure to fund new nuclear construction. Since financing costs are such a large proportion of the total construction cost of new NPPs, it is wise to fund as much of the project as possible through pre-charges and cash on hand.

4 HOW TO FINANCE NEW NUCLEAR BUILD IN LIBERALISED MARKETS

Under the former regulated utility regime and regulatory arrangements, many of the risks associated with power plant construction costs, operating performance, fuel price changes, and other factors were borne by consumers rather than investors. The current context for new nuclear build in power markets is significantly different with producers bearing much of the risks unless some are transferred onto other stakeholders through long term contracts and/or innovative financing arrangements.

A project for potential new nuclear power plant in liberalised markets will face a number of hurdles associated with the specificities of the technology and the legacy of past experiences. Nuclear power suffers indeed from some specific risks: the regulatory risk associated with the instability of safety regulations and design licensing; the policy risk where electoral cycles could undermine the commitment to nuclear power and the development of nuclear waste disposal facilities; and the construction and operation risks associated with the necessary re-learning of the technology. Besides, the large size of a nuclear project and the capital intensity of the technology make it relatively more sensitive to some critical market risks such as the electricity price and volume risks.

The contractual and financing choices for new nuclear build in typical market cases can be:

- The decentralised market is based on a project finance approach. The critical factors enabling such financing structure are the federal loan guarantees, federal tax credits, and long term fixed price contracts with credible counterparts;
- The Nordic market, wherein the Finnish TVO project to build an EPR uses an hybrid financing approach. The project relies on two special arrangements: a turnkey contract by which the constructor bears a large part of the construction and performance risks, and the financing by a consumers' consortium whose members will in return pay electricity at cost-price over the life of the plant;
- The imperfectly reformed market, wherein the project is managed and lead by the large size and vertically integrated historical incumbent, using a corporate financing approach;
- Finally, the case of oligopolistic markets of mid-size vertical companies or of small markets dominated by incumbent companies developers and their potential lenders in such markets would likely seek to share costs and risks by e.g. investing in a producers consortium, and would search to have some market risks transferred onto the state.

In these cases there remain many critical factors specific to each country's industrial and regulatory environment, there is no optimal "once-for-all" contractual and financing arrangement for investing in nuclear in liberalised markets.

In the perspective of project financing of new nuclear plants, loan guarantees by government and power purchase agreements at fixed price for almost all the off-take power will likely be required. Turnkey contract for the FoAK reactors could also provide a guarantee during the construction phase, followed by refinancing for the plant operation phase. Nuclear build in liberalised markets is going to bring some new light on some critical issues associated with the maturing of electricity markets.

Improving prospects for financing means understanding financing risks, establishing ownership and effecting mitigation and there may be no financial 'silver bullet': Nuclear perceptions and realities also impact on financing.

5 ELECTRICITY GRID AND NPP UNIT CAPACITY

Considering that the nuclear power plant will be integrated into the national electrical power grid and into the local and -wider regional environment, the selection of the station capacity should take into account the implications of the necessity to strengthen the electrical connections to the other nodal points of the electric grid, to the neighbouring countries, and of the necessary legal and commercial agreements with those countries.

The size of a nuclear unit in this context refers to the maximum electrical power that it can deliver to the transmission system. Partly driven by economies of scale, there has been a steady increase in the size of new nuclear units, so the designs of nuclear units that are currently available from international nuclear plant vendors are large, generally greater than 1,000 MW.

Consequently, a first nuclear unit built today is almost certainly going to be the largest single generating unit in the system to which it is connected. This may represent an issue if the system is relatively small such as:

- The need to control the large and rapid changes in frequency, voltage and power flow that will occur after a trip of the nuclear unit or if a fault in the transmission system disconnects the nuclear unit
- The need to have sufficient generation to meet electricity demand during periods that the nuclear unit is shut down, whether for planned maintenance or following a fault or unplanned trip
- From the point of view of the NPP, the need to ensure that a trip of a nuclear unit will not cause a loss of offsite power to the NPP, and the voltage and frequency of the offsite supply will remain within the acceptable range.

If the current or future electricity demand of the country is too small, and there is not a reasonable prospect of developing strong grid connections to neighbouring countries, then a conclusion of a feasibility study of the introduction of nuclear power in country could be that the country is not able to consider nuclear power until smaller nuclear units become available.

5.1 NPP and Electricity Generation Planning

The first step in working on generation plan is to collect, summarize and review all relevant information on the present state of power generation capacity [8]. Power system expansion planning involves analyzing, evaluating and recommending what new facilities and equipment must be added to the power system in order to replace worn-out facilities and equipment and to meet changing demand for electricity. Planning the expansion of the generation component of a power system has to be carried out taking into account two other major components of the system – transmission and distribution.

The most important concept in a definition of the energy planning process is that its ultimate purpose is to provide information to decision-makers.

Power generation plan can be successfully completed only if necessary inputs coming from Electricity demand analysis and from certain parts of other energy sector analysis are adequately provided. The obtained results will serve as one of the inputs for transmission and distribution, as well as for environmental impact analysis.

The goal of electric power systems expansion planning is to determine the optimal pattern of system expansion to meet the electricity requirements over a given period. Computer assisted modelling forms are the core of the approach to energy analysis and planning. Energy planners or policy analysts design future development trajectories of the principal drivers of the energy system 20 to 50 years into the future, and by using the energy planning tools, derive profiles of energy service demands and optimal supply mixes. Critical policy and investment aspects of different energy strategies can be defined, undesirable consequences can be identified, and the most cost effective approach to meeting future energy needs can be determined.

The Wien Automatic Simulation Planning Package (WASP) [9] helps to find the economically optimum expansion plan for a power generating system for up to 30 years, within constraints specified by the planner. The model evaluates many combinations of candidate generation projects to obtain the least-cost expansion plan (optimal solution) for a given period. The outputs of WASP include the alternative expansion plans and their Present Value (NPV) costs, annual financing requirements and summary reports. WASP is a cost minimization tool whose objective function is to generate the power planning expansion plan with the lowest present worth cost for the planning period.

WASP is designed to find the economically optimal long-term generation expansion policy for an electric utility system within user-specified constraints by utilizing several mathematical tools: probabilistic simulation, linear programming and dynamic programming. The optimum is evaluated in terms of minimum discounted total costs. Each possible sequence of power units added to the system (expansion plan or expansion policy) meeting the constraints is evaluated by means of a cost function (the objective function) that is composed of: Capital investment costs, Salvage value of investment costs, Fuel costs, Fuel inventory costs, Non-fuel operation and maintenance costs, Cost of the energy not served. WASP was successfully used as a planning tool in many Generation Investment Studies.

5.2 Example of introducing NPP in small electricity grid

The uptake of Nuclear power technology has been growing over time across different countries and regions. Various countries without existing nuclear power technology in their power systems have expressed interest in investing in initial nuclear power projects, while developed countries with existing nuclear plants have been expanding their capacities. Design and development of nuclear reactors is a major undertaking, which requires significant technical and financial resources. In recent decades the nuclear power industry has managed to improve the output of existing nuclear power plants quite dramatically. The net capacity of recently reviewed nuclear reactors in a joint 2010 study by the International Energy Agency (IEA) and the OECD Nuclear Energy Agency (NEA) [2], finds that nuclear reactors ranges from 954 MWe in the Slovak Republic to 1,650 MWe in the Netherlands, with the largest site to be constructed in China consisting of 4 units of 1,000 MWe each, (OECD, 2010). Owing to differences in country-specific financial, technical and regulatory boundary conditions, overnight costs for the new nuclear power plants currently under consideration in the OECD area vary substantially across the countries, ranging from as low as 1,556 USD/kWe in Korea (noting the generally low construction costs in that country, as well as its recent experience in building new reactors) to as high as 5,863 USD/kWe in Switzerland, with a standard deviation of 1 338 USD/kWe, median of 4,102 USD/kWe and mean of 4,055 USD/kWe. Table 1 provides an overview of nuclear generation costs for different technologies used in various countries [2].

The OECD 2010 study [10] assumption for the average lifetime load factor for calculating the levelized costs of nuclear generation is 85%. The load factor is an important performance indicator measuring the ratio of net electrical energy produced during the lifetime of the plant to the maximum possible electricity that could be produced at continuous operation. In 2008, globally, the weighted average load factor reported for PWRs (a total of 265 reactors) was 82.27%, for BWRs (total of 94 reactors) it was 73.83%, with larger reactors (>600 MWe) exhibiting on average a 2% higher load factor than smaller reactors.

Table 1 Nuclear generation costs for different technologies used in various countries [2]

COUNTRY	NUCLEAR TECHNOLOGY	USD/kWe
Belgium	EPR-1600	5,383
Czech Republic	Pressurised Water Reactor (PWR)	5,858
France	EPR	3,860
Germany	PWR	4,102
Hungary	PWR	5,198
Japan	Advanced Boiling Water Reactor (ABWR)	3,009
Korea	Optimised Power Reactor (OPR-1000)	1,876
	APR-1400	1,556
Netherlands	PWR	5,105
Slovak Republic	WER	4,261
Switzerland	PWR	5,863
	PWR	4,043
United States	Adv Gen III+	3,382
Brazil	PWR Siemens/Areva	3,798
China	Chinese Pressurised Reactor (CPR-1000)	1,763
	CPR-1000	1,748
	AP-1000	2,302
Russia	WER-1150	2,933

The decommissioning costs of the nuclear power plants reviewed in this study have also been included in the levelized costs calculation. Where no country-specific cost figure was provided, a generic study assumption of 15% of the overnight cost has been applied to calculate the costs incurred during all the management and technical actions associated with ceasing operation of a nuclear installation and its subsequent dismantling to obtain its removal from regulatory control. In particular, the fact that for nuclear power plants decommissioning costs are due after 60 years of operation and are discounted back to the commissioning date, makes the net present value of decommissioning in 2015 close to zero, even when applying lower discount rates or assuming much higher decommissioning costs.

5.2.1 Long term plan - Screening curves of power plants

The screening curve technique is an approximate method that captures major tradeoffs between capital costs, operating costs and utilization levels for various types of generating capacity in the system. The screening curve method expresses the total annualized electricity production cost for a generating unit, including all capital and operating expenses, as a function of the unit capacity factor. This approach is especially useful for quick comparative analyses of relative costs of different electricity generation technologies. Figure 1 shows the screening curves for the reference discount rate (10%) scenario in our example. The results of the screening curve analysis indicate that the Nuclear and coal are suitable for base load operation.

In Screening of Candidate Plans fuel prices for thermal generation unit cost was: Crude Oil Price = 100 US$/bbl, Coal Price = 120 US$/tonne, Natural Gas = 10.1 US$/GJ [3-7].

The screening curves show the yearly cost of one firm kilowatt according to the load factor of the power plant and can show ranking of candidate projects. For a given load factor, we obtain the levelized cost of energy (LCOE) related to this load factor.

The candidates are categorized according to the type of supply they are designed for; either base load or peak load. Figure 1 show the screening curves for the discount rate 10%. The screening curves shows that nuclear plant are the most economically attractive for capacity factor higher than 43% in base case of 10% discount rate. In the case of 7% discount rate this is the case even for capacity factor for nuclear more than 36% and in the case of 12% discount rate this is the case for capacity factor for nuclear more than 50. As a conclusion, this means that the expansion plan designed by the WASP model will first resort to nuclear resources as far as possible. The capacity needed in addition to nuclear should be supplied by coal, natural gas and gas oil.

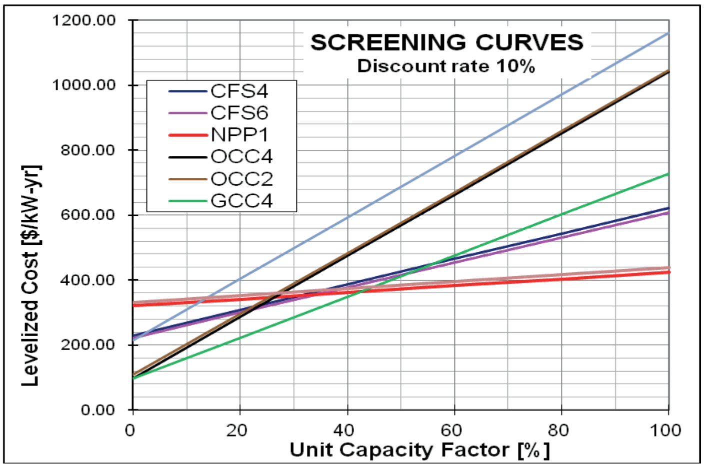

Figure 1 Screening of candidates at 10% discount rate

5.2.2 Long -term optimization: WASP Least Cost Expansion Plan Example

The objective of analysis in our example was is to analyze possible long-term development options of the small electric power system in the period for 30 years and to analyze possible introduction of nuclear power plant in relative near future. The analysis involved systems planning studies for the least-cost generation expansion planning. Very well-known and widely accepted computer model were used in the analysis: the WASP-IV model for the optimization of long-term system development [9].

In Least Cost Expansion Plan candidate generation resources considered in the system expansion plan include, hydro, coal, oil-fired, natural gas and nuclear power plants. The load forecast covers a period of 30 years. It sets out the following in Base Case Scenarios from year 1 to year 30 total increase of peak load in MW is around 19 GW (from 1 300 MW in year 1 to 20 600 MW in year 30) - Figure 2. During whole study period Load factor is 65 %.

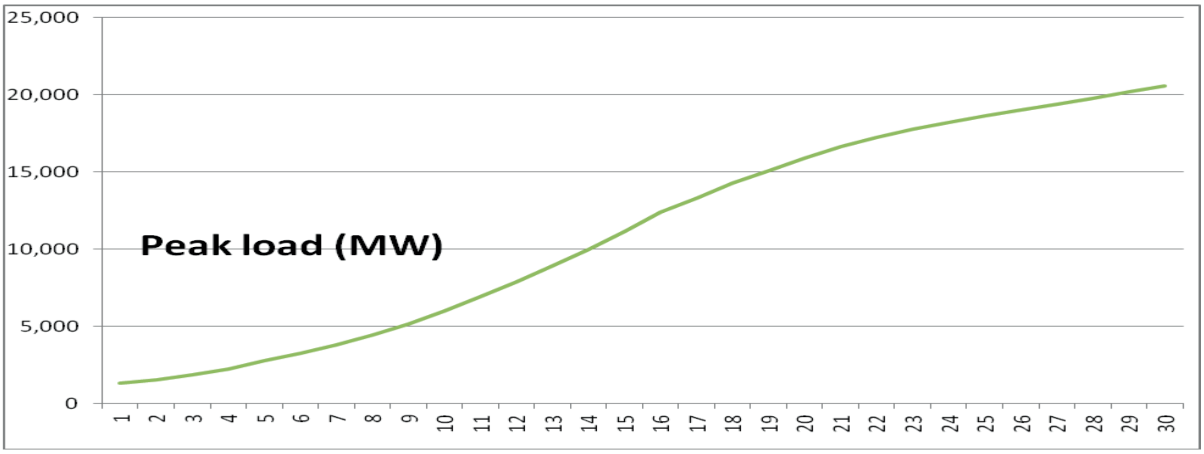

Figure 2 Peak load for whole study period

The candidate plats were: steam coal plants, nuclear power plants, gas oil combined cycle plants and natural gas combine cycle plants. For candidate thermal power plants were selected following plants with net capacity (nuclear plant 600 MW just in some cases): Steam Coal plant 400 MW, Steam Coal plant 600 MW, Nuclear Power Plant 1000 MW, Gas oil combined cycle 470 MW, Gas oil combined cycle 210 MW, Natural gas combine cycle 450 MW, *Nuclear Power Plant 600 MW*.

For whole study period were used next fuel costs: Heavy fuel oil 4.3 US$/GJ, Gas Oil 15.2 US$/GJ, Diesel Oil 15.2 US$/GJ, Crude 16.1 US$/GJ, Imported coal 4.2 US$/GJ, HFO - future candidate 11.3 US$/GJ, Nuclear fuel 0.65 US$/GJ, Natural gas 10.1 US$/GJ [3-7]. LOLP-loss of load probability was 0.27% (1 day in year) from year 7. All costs were expressed in U.S. dollars. The discount rate applied for the present worth analysis was 10%, No real cost escalation was assumed for the fuels. The sinking fund depreciation method was used to calculate the salvage value of candidate plants committed during the study period. The economic loading order of existing and candidate generating units was used in all analyzed scenarios. The upper and lower values of the planning reserve margin were specified exceeding the peak load from 15% to 45%, in order to simulate every possible system configuration that can adequately meet the system demand and reliability constraints. Sensitivity studies were performed for different LOLP values, and the cases with no LOLP constraints were also examined. The energy-not-served (ENS) cost for the Base Case analysis was estimated at 1.00 $/kWh.

There were some constraints applied in all WASP simulations because to get realistic picture for candidate NPP 1000 MW: the first NPP is open in year 8 and, additional NPP as candidate in year 14, 19, 23 and 26; possible to add one natural gas combine cycle (NGCC) plant in year 16, 17, 20, 23, 26 and 29. In some cases there were two nuclear power plants as candidate NPP 1000 MW and 600 MW.

Figure 3 shows system load and WASP optimal solution for whole study period of 30 years in Base Case conditions. Figure 4 shows total capacity added in each year for whole study period. Figure 5 shows total capacity added in NPP in each year for whole study period.

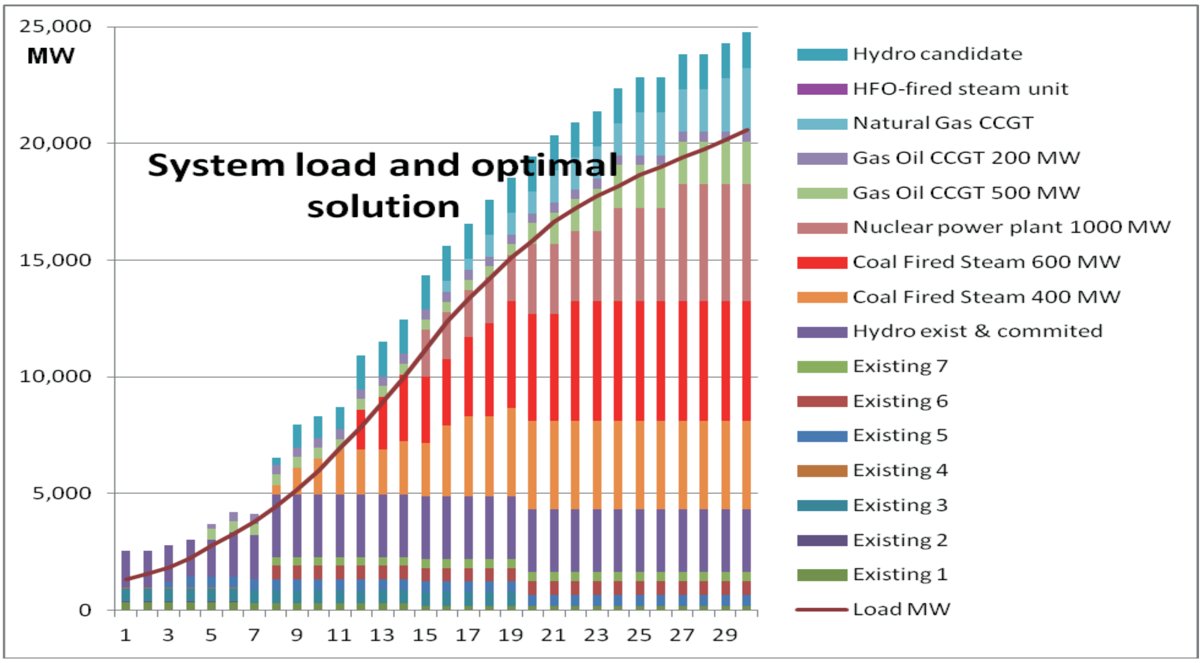

Figure 3 System load and WASP optimal solution for whole study period for 30 years in Base Case conditions

Some sensitivity analysis was done for some cases that have limitations on coal power plants: Limitations on coal new plants about total 3 000 MW for whole study period; Limitations on coal 1 plant in 2 year and total 3000 MW for whole study period; Limitations on coal new plants about total 3000 MW; no NGCC for whole study period; Limitations on coal 1 plant in 2 year and total

3000 MW; no NGCC for whole study period; Limitations on coal new plants, no new coal plants until 2024.

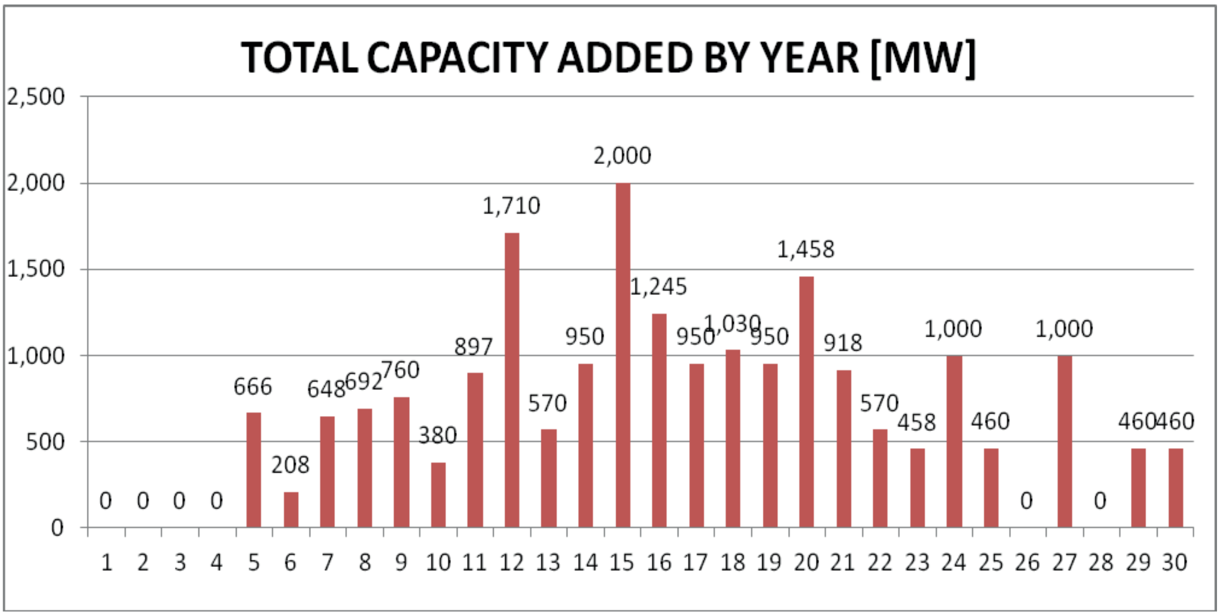

Figure 4 Total capacity added by year [MW] - BASE Case (MED)

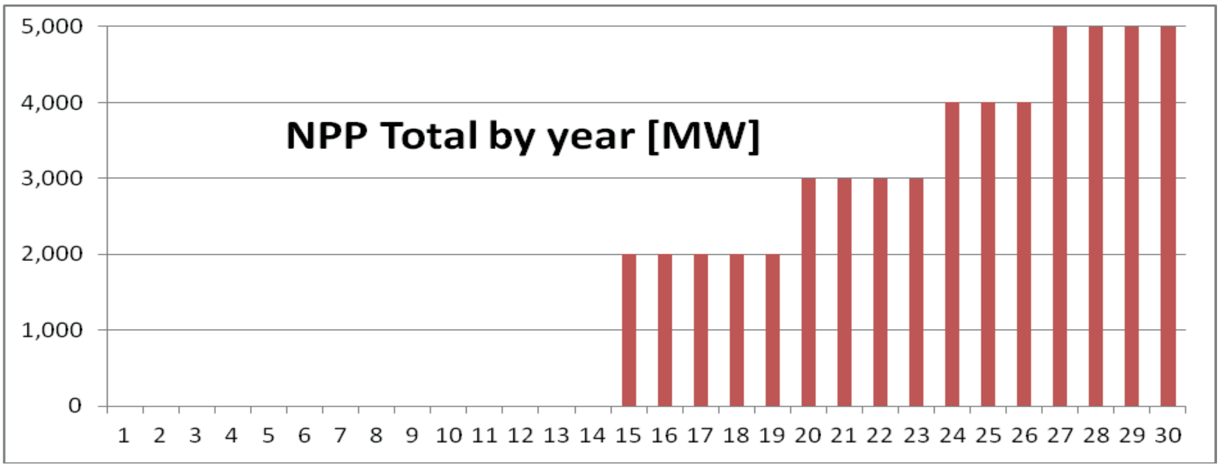

Figure 5 Total installed capacity in NPP by year [MW] - BASE Case (MED)

5.2.3 Some conclusions and comments from analysed example

Results from Base Case Scenarios in our example show:

- main competition for base power production is between nuclear and coal power plants
- in case that only candidate NPP is 1000 MW the first year of operation for the first unit is year 14
- in all cases after year 14 all five candidates NPP 1000 MW are selected in optimal solution at the end of study period
- in case that candidates NPP are 1000 MW and 600 MW the first year of operation for the first unit for 600 MW is year 9 for discount rate of 10% and 12% and year 8 in the case of 7%.
- in case that candidates NPP are 1000 MW and 600 MW the first year of operation for the first unit for 1000 MW is year 13
- in case that candidates NPP are 1000 MW and 600 MW the objective function and total costs of operation are less than in case when only candidate is NPP 1000 MW.

Conclusions from Base Case Scenarios under different constrains:

- in case of constraints on coal (new coal plants about total 3000 MW): the introduction of the first unit for 1000 MW NPP is year 12 (in base case is year 14)

- in case of constraints on coal construction of one plant in 2 year and total new plants 3000 MW: the introduction of the first unit for 1000 MW NPP is year 10 (in base case is year 14)
- in case of constraints on new coal plants about total 3000 MW: no natural gas plants-NGCC, the introduction of the first unit for 1000 MW NPP is year 12 (in base case is year 14)
- in case of constraints on coal construction of one plant in 2 year and total new plants 3000 MW: no natural gas plants-NGCC the introduction of the first unit for 1000 MW NPP is year 10 (in base case is year 14)
- in case of constraints on coal new plants about total 3000 MW and in case that candidates NPP are 1000 MW and 600 MW: the first year of operation for the first unit for 1000 MW is year 13, for 600 MW is year 9
- in case of constraints of forced the first 1000 MW NPP in year 9, the objective function is higher than in base case but not too much just less than 1%.

Results from Sensitivity on investment cost for NPP in Base Case Scenarios (NPP investment for values: 1700 – 4000 USD/kW) show:

- in optimal solution for base condition the first new 1000 MW NPP in year 14
- for NPP 1000 MW investment cost between 1700 and 1880 USD/kW the first new 1000 MW NPP in optimal solution is in year 11
- for NPP 1000 MW investment cost between 1890 and 3005 USD/kW the first new 1000 MW NPP in optimal solution is in year 14 and optimal solution is same like in base case
- for NPP 1000 MW investment cost between 3010 and 3400 USD/kW the first new 1000 MW NPP in optimal solution is in year 16
- for NPP 1000 MW investment cost above 3500 USD/kW there is no 1000 MW NPP in optimal solution

From this analysis can be seen that investment cost of 1000 MW NPP can influence optimal solution and this parameter is one of the most important in decision for introduction of nuclear option and must be define as soon as possible to make good decision for possible construction of nuclear power plants.

Results from Sensitivity on Constraints on coal new plants, different number of candidates until year 12 in Base Case Scenarios shows:

- number and year of introduction new coal candidate plant influence optimal solution regarding introduction of 1000 MW NPP
- if only two new coal plants are as candidate until 11 (after that 4 coal plants are candidates) the first 1000 MW NPP is in optimal solution in year 10
- any limitation to new coal plats until 12 introduce the first NPP is in optimal solution in year 10/11
- this analysis shows that policy regarding introduction of new coal plants should be carefully defined and this decision highly influence optimal solution for introduction of nuclear power plant 1000 MW

Results from sensitivity on increase base case investment costs for Coal Power Plants (increase for 100 to 700 USD/kW) in Base Case Scenarios:

- increase of base case investment costs for candidate coal power plants from 100 to 390 USD/kW do not influence optimal solution regarding 1000 MW NPP
- increase of base case investment costs for candidate coal power plants from 400 to 700 USD/kW has small influence to optimal solution regarding 1000 MW NPP and just introduce 1000 MW NPP one year earlier from 14 to 13.
- this analysis shows that investment cost of new coal plants does not too much influence optimal solution regarding introduction of nuclear power plant 1000 MW and that main factor in selecting new candidate power plant until year 14 is install capacity of candidate plant.

In almost all cases when candidate NPP was 1000 MW the first 1000 MW NPP in optimal solution was selected by model in year 14 and later in the year when it is next additional NPP available.

In cases when candidates NPP were 1000 MW and 600 MW the first NPP were selected by model mostly in year 10 or in some cases year before.

These are logical solutions for Least Cost Power Development Plan done by WASP programme because there is large capacity additions of committed thermal plants in year 6 and if we look to graph for system load in all cases and compare with existing installed capacity plus committed plants it can be seen that is no space for addition of large unit 1000 MW. In that cases program select coal power plants until there is enough large new demand.

Even nuclear power plant is selected by programme relatively late, screening curves show that nuclear is very competitive and in the cases with unit of 600 MW it is the best options. But the problem is in case of small load in our example and also because continues relative high growth (but still in absolute term low) and model is taking smaller unit to fill the gap and there is difficult to find place for large unit. Because of that after year 14 nuclear 1000 MW become the best options and model wants even more than five NPP.

Under the characteristics as selected for the study nuclear is competitive in simple comparison but in real power system it is not always optimal solution for small power system in case of large NPP units.

Results, under conditions defined in study, is very robust and changes in discount rate, investment cost of coal plant (should be more than 3000 USD/kW what is unrealistic) etc. do not change results. Finally, main conclusion from example is that nuclear option is economically feasible (even the best option) but in very small system that can be problematic for large unit of 1000 MW.

6 CONCLUSIONS ABOUT NPP FINANCING IN SMALL GRID

It is clear that strong and consistent government support is an essential prerequisite for initiating or expanding any nuclear power programme, as part of a long-term national energy strategy. Otherwise investors will be open to the risks of sudden policy shifts as governments change, potentially jeopardising their investment. Specifically, governments need to put in place an efficient regulatory framework, which allows appropriate opportunities for public involvement but allows clear and definite decision making within a reasonable timescale. Additional legal frameworks dealing with liability issues, radioactive waste management and decommissioning are also necessary.

Electricity market risks can be mitigated by long-term agreements with large consumers or electricity distributors. In some cases, direct involvement of such consumers in the structure of the project may be an attractive option.

Corporate finance is the most likely generally applicable model for new NPPs. Large, financially strong utilities will be best able to finance new NPPs especially if they are vertically integrated. They will be able to attract loans as required, backed by their existing assets. In countries where such utilities do not exist, the need for direct government support to share in the construction risks is likely to be all the greater. It appears that there is very little likelihood in the foreseeable future to finance a new NPP by using non-recourse or “project” financing (i.e. using only the NPP project itself as collateral).

It is important to note that the financing of an NPP need not remain static over its lifetime, and in particular that refinancing is likely to be possible once the plant has successfully entered operation. At that stage, with construction risks removed and with the plant expected to generate steady revenues over several decades, an NPP could be an attractive investment opportunity for investors with a long term perspective.

The important question examined in developing NPP project is which approach can be used to finance nuclear power plants to be compatible with current utility and financial market conditions and specially in country with small economy. Also deeper understanding of the risks involved in project finance and risks evolution over time is important for both practitioners and policymakers. In particular, further research in this area might help in the implementation of risk sensitive capital requirements providing market participants with the incentives for a prudent and, at the same time, efficient allocation of resources across asset classes.

Main competition for base power production is between nuclear and coal power plants

From analysis of presented example can be seen that investment cost of 1000 MW NPP can influence optimal solution and this parameter is one of the most important in decision for introduction of NPP and must be define as soon as possible to make good decision for possible construction of nuclear power plants. This analysis shows that investment cost of new coal plants (in reasonable range) does not too much influence optimal solution regarding introduction of NPP and that main factor in selecting new candidate power plant is install capacity of candidate plant in time when load is still small.

Even nuclear power plant is selected by programme relatively late; screening curves show that nuclear is very competitive. But the problem is in case of small load in our example and also because continues relative high growth (but still in absolute term low) there is need for new capacity optimal solution is taking smaller unit to fill the gap and there is difficult to find place for large NPP unit.

Under the characteristics as selected for the study nuclear is competitive in simple comparison (screening of candidates) but in real power system it is not always optimal solution for small power system in case of large NPP units. Conclusion from presented example is that nuclear option is economically feasible (even can be the best option) but in very small system that can be problematic for large unit of 1000 MW.

In developing NPP project should be identified the special circumstances for financing nuclear power project in relatively small economy.

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